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THESIS

DUAL-PHASE NOZZLE FLOW

by

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October 1982

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Dual-Phase Nozzle Flow

by

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requirements for the degree of

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ABSTRACT

A review of the dual-phase power system was made. This study focused on the multi-component nozzle of this dual-phase system. First, an existing computer code predicting the nozzle performance was updated, and second a series of experimental tests on a variable area, two-dimensional nozzle was performed to verify the computer code.

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I. DUAL-PHASE CYCLE

The dual-phase nozzle is a key element in the dual-phase engine concept. This nozzle will be studied in detail, but first a review of the dual-phase cycle will be carried out from information obtained from References 1 and 2.

Reference 1 describes the dual-phase engine. It is a new concept which operates on a mixture of two fluids or two phases of one fluid. This cycle employs a high-torque/low-rpm impulse turbine which eliminates the requirement for speed reduction needed in a conventional steam turbine. This allows for direct drive of a ship's propeller with no gear reduction. This is ideally suited for marine propulsion, reducing weight, noise, and volume.

The dual-phase concept is a modified Rankine cycle with subtle differences of extreme importance. In a normal steam turbine the working fluid enters a turbine through a nozzle where the kinetic energy of the working fluid is converted to a mechanical form. The dual-phase system introduces a second fluid prior to entry into the nozzle. This fluid is of higher vapor pressure than the steam and therefore remains in the liquid state throughout the cycle. Section A will describe this two-component cycle while section B will do the same for a single-component system. The dual-phase

system can be divided into the two groups illustrated in Figure 1. Single-component flow can be further divided into three categories.

A. TWO-COMPONENT

A two-component mixture is one in which the low vapor pressure liquid and a high vapor pressure liquid are of different chemical compounds. Some fluid combinations which have been considered are steam-krytox, steam-caloria, steam-lead, bismuth eutectic, and dow-therminol. A schematic flow diagram and process representation on the T-S diagram are shown in Figures 2 and 3 for the two-phase engine cycle using a "two-component" mixture. The liquid phase is lithium carbonate and vapor phase is steam. To illustrate the overall advantages of the two-phase engine cycle a discussion on the theory of operation will be presented using a two-component mixture and Figures 2 and 3.

The major component of the dual-phase system is the nozzle. A mixer area is located prior to the nozzle inlet. A high vapor pressure liquid is placed in contact with the low vapor pressure liquid in this area. A high pressure vapor liquid mixture is formed. Since the temperature of the liquid is greater than temperature of the water, heat is transferred to the water causing it to vaporize to point 1. Figure 4 illustrates the temperature and state point from the inlet of the mixture area to the nozzle exit. This mixture is

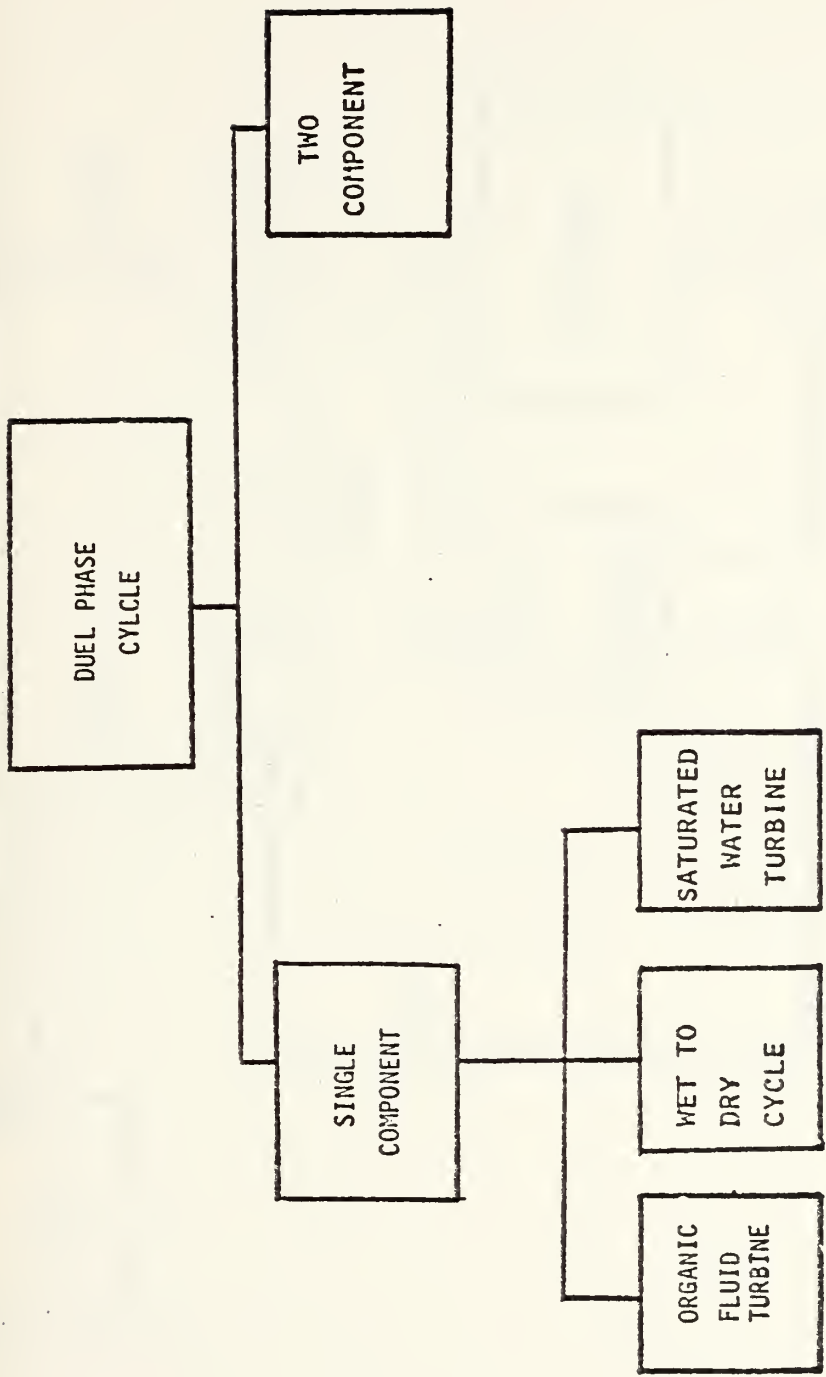


Figure 1. Division of the Dual-Phase Cycle

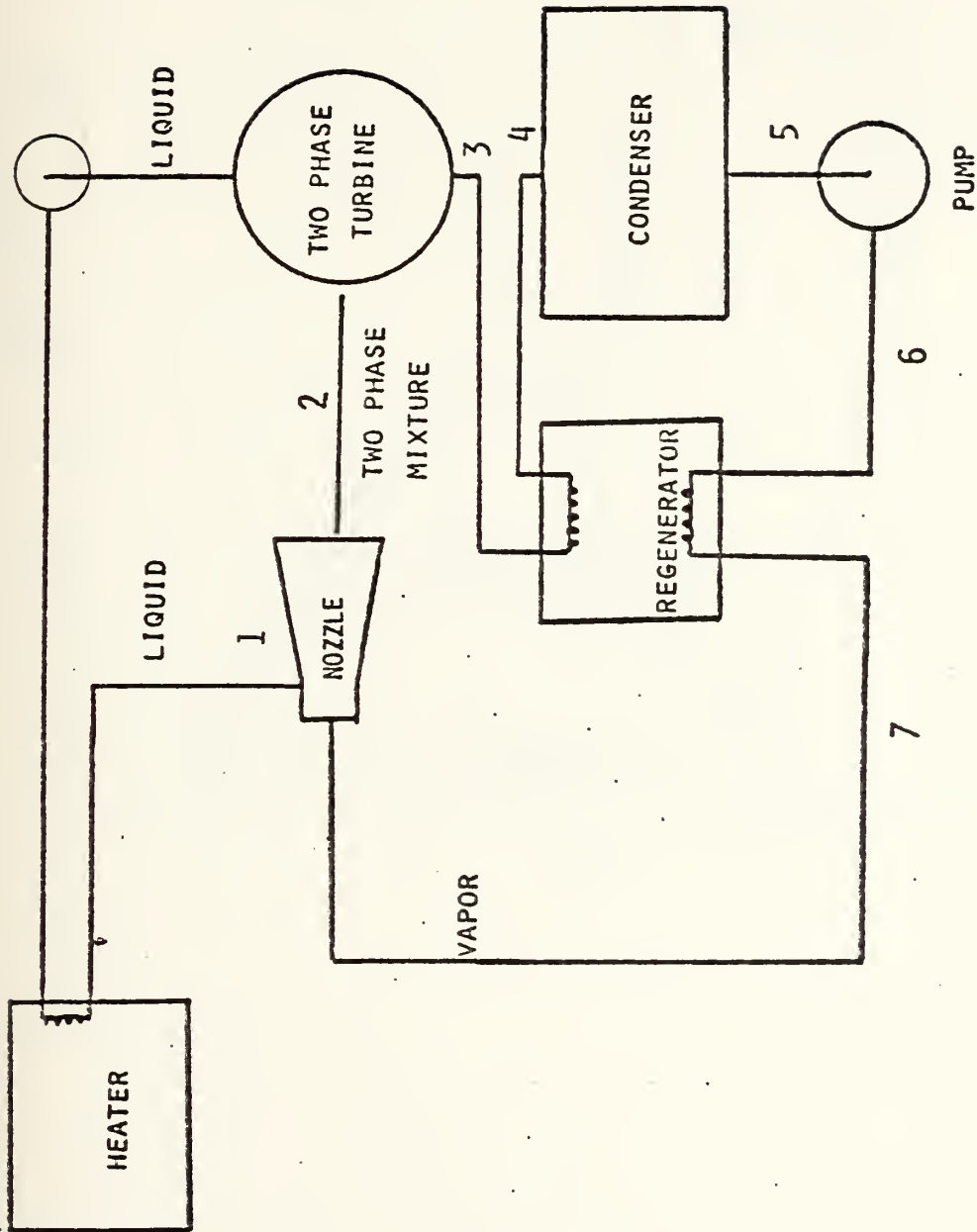


Figure 2. Dual-Phase Two-Component System

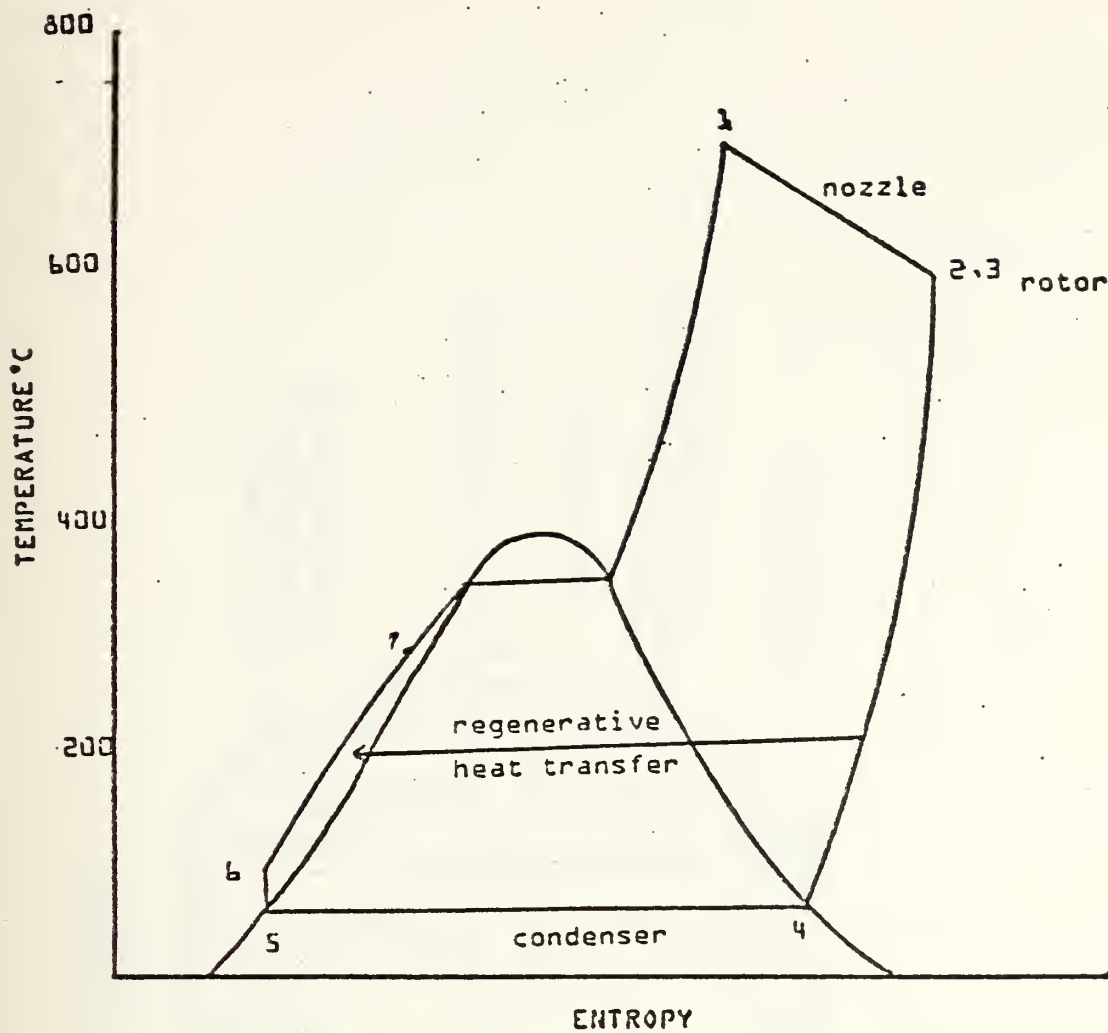


Figure 3. Dual-Phase Two-Component T-S Diagram

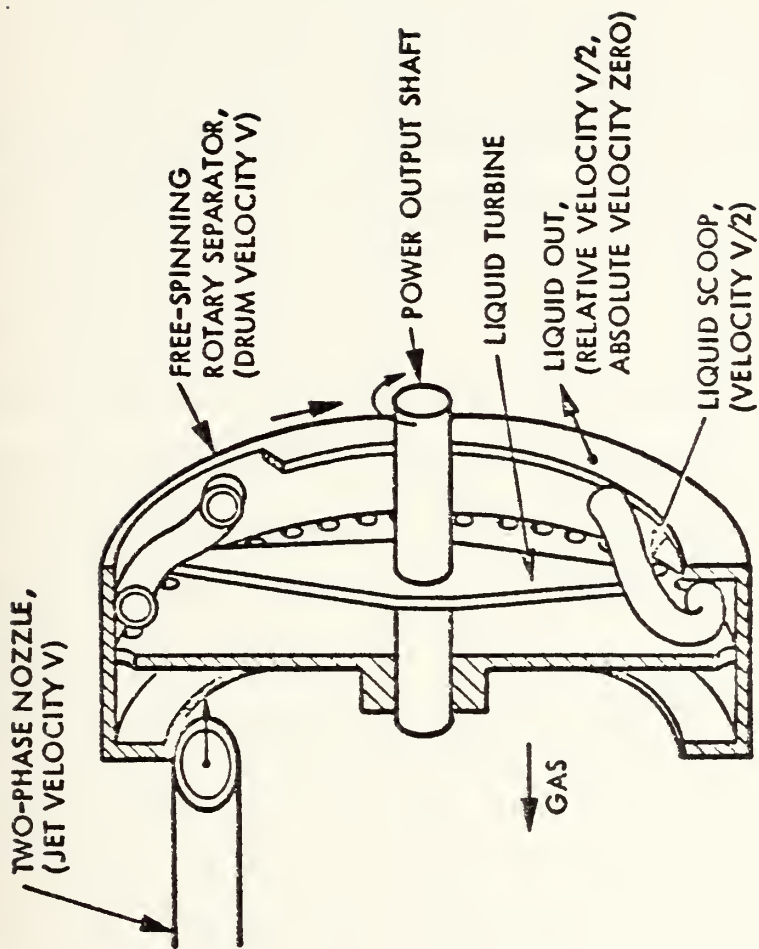
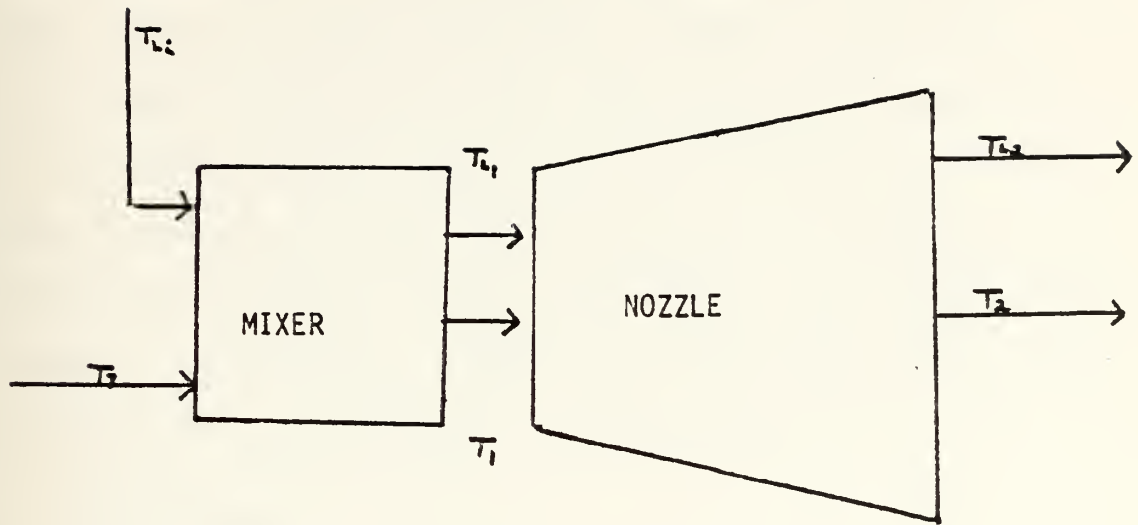


Figure 4. Liquid Impulse Turbine Schematic

expanded to a low pressure at the nozzle exit. The expanding vapor transfers momentum to the liquid droplets, while the droplets transfer heat to the vapor. This tends to approach isothermal expansion through the nozzle, point 2. After leaving the nozzle, the liquid droplets are separated from the vapor by a rotary separator located on the turbine. The rotating drum turns at close to the nozzle's exit velocity. Hence there is very little friction loss between the separated liquid and the drum wall. The centrifugal acceleration produces a very clean separation of vapor and liquid. The liquid traveling with the rim of the rotating drum transfers axially through holes in the separator disc and subsequently enters the liquid turbine proper. The kinetic energy of the liquid is converted to shaft horsepower by the liquid turbine. Figure 5 illustrates the dual-phase liquid impulse turbine assembly. The vapor remains superheated as a consequence of the heat transfer from the liquid. The vapor flows from the separator, point 3, through a regenerator where heat is transferred to the condensate. The vapor is condensed, point 5; pumped to nozzle pressure, point 6; and passed through the regenerator for heating. Heat is added between point 6 and point 1 in two methods. The regenerator adds heat to the condensate by using the steam from the turbine rotor, point 7. The remainder of heat, point 7 to 1, is added by the heated liquid mixed with the condensate in the mixer. The water is vaporized by direct-contact heat transfer.



where

- T_{L_i} = Temp of liquid entering mixer
- T_7 = Temp of water entering mixer
- $T_{L_i} > T_1$
- T_2 = Temp of steam leaving the nozzle
- T_{L_2} = Temp of liquid leaving the nozzle

Figure 5. Temperature & State Point Diagram for the Mixture & Nozzle

In the nozzle most of the thermal energy of the steam is converted to kinetic energy of the liquid droplets. This acceleration of the liquid by the vapor in the two-phase nozzle provides the kinetic energy to drive the liquid impulse turbine. The liquid velocities involved are relatively low as compared to velocity of the vapor. Thus, the output of the impulse hydraulic turbine will be high torque/low rpm. This conversion of the liquid kinetic energy to shaft power at high torque with low rpm appears to have direct application to naval propulsion.

B. ONE-COMPONENT

A one-component system is one in which the working fluid is of the same chemical compound. One of the simplest dual-phase one-component systems is illustrated in Figures 6 and 7. The working fluid is heated to saturation temperature by some type of heat source. Heat sources applicable to this case are geothermal power plants, engine exhaust, industrial waste-heat recovery, and bottoming cycles for steam and gas turbine plants. This working fluid, at saturated liquid conditions, with small amounts of vapor is expanded through a two-phase nozzle. As the expansion process takes place, the liquid partially vaporizes and accelerates the remaining liquid phase in the nozzle. The dual-phase mixture enters the rotary separator and the same process occurs as mentioned in section A. Since the liquid phase is of a much higher

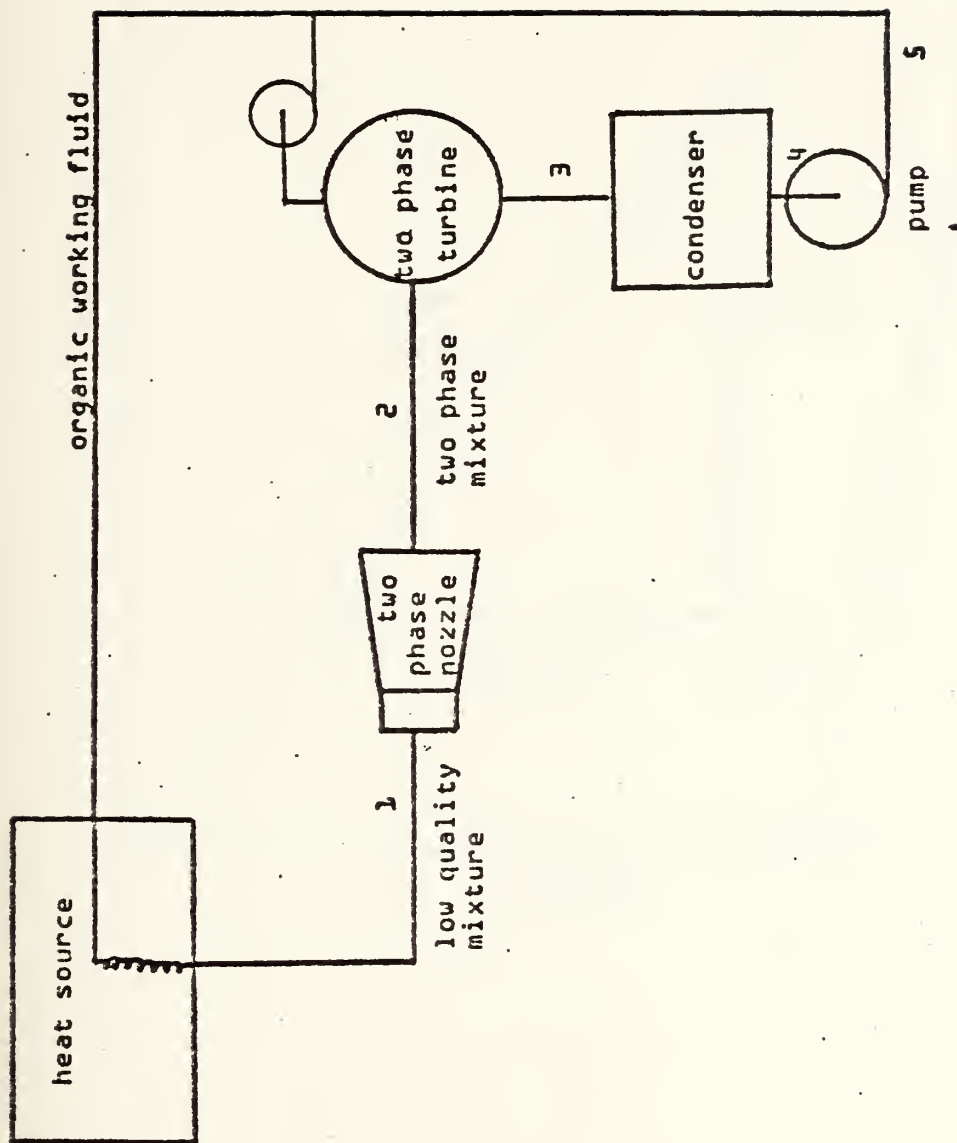


Figure 6. Dual-Phase Single-Component System

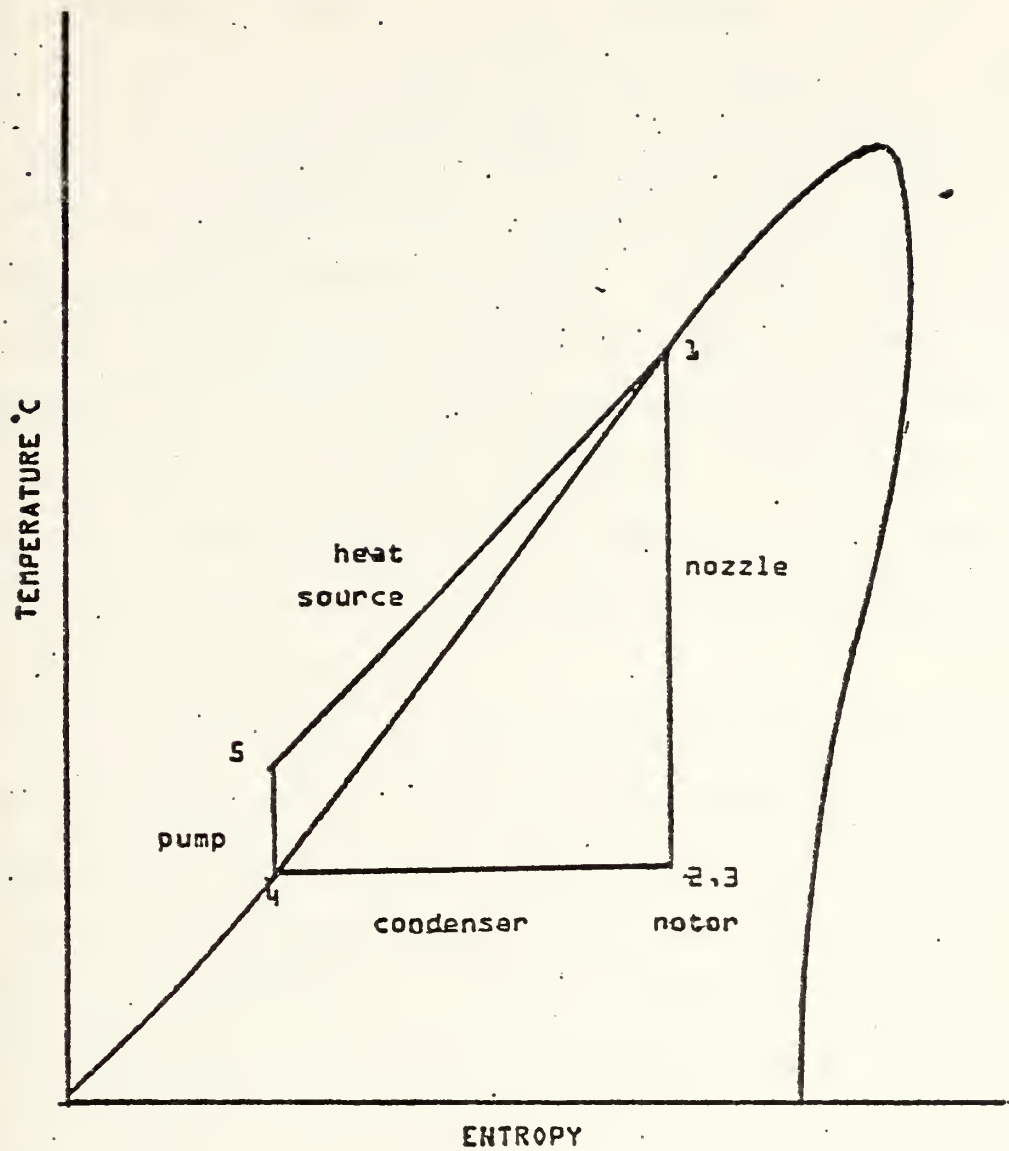


Figure 7. Dual-Phase Single-Component T-S Diagram

density than the vapor, the liquid velocities are relatively low as compared to the velocity of the vapor. Thus the output of the turbine will again have high torque at low rpm. After leaving the turbine the vapor mixture is condensed and the condensate is pumped back to the heat source. The cycle is shown on a T-S diagram in Figure 6. The state points are numbered to correspond with Figure 5. The dual-phase nozzle expansion takes the fluid from a saturated liquid, point 1, to a dual-phase flow, point 2. The flow is decelerated in the rotor; condensed, point 4; and pumped back to nozzle inlet pressure at point 5. The liquid is then reheated by the source fluid to point 1.

Another application of the one-component two-phase cycle is the wet-to-dry cycle. If the initial temperature of the working fluid is sufficiently high and the saturation curve has a positive saturated liquid slope the working fluid can be expanded to dry vapor. Figure 8 is the T-S diagram for a wet-to-dry cycle. The fluid is expanded from saturated liquid at point 1 to saturated vapor at point 2. The vapor drives an impulse rotor and leaves the rotor slightly superheated at point 3. The vapor is condensed to point 4 and pumped back to the nozzle inlet pressure at point 5.

C. ADVANTAGES

The advantage of the dual-phase cycle with respect to marine application is the ability to achieve low shaft speed

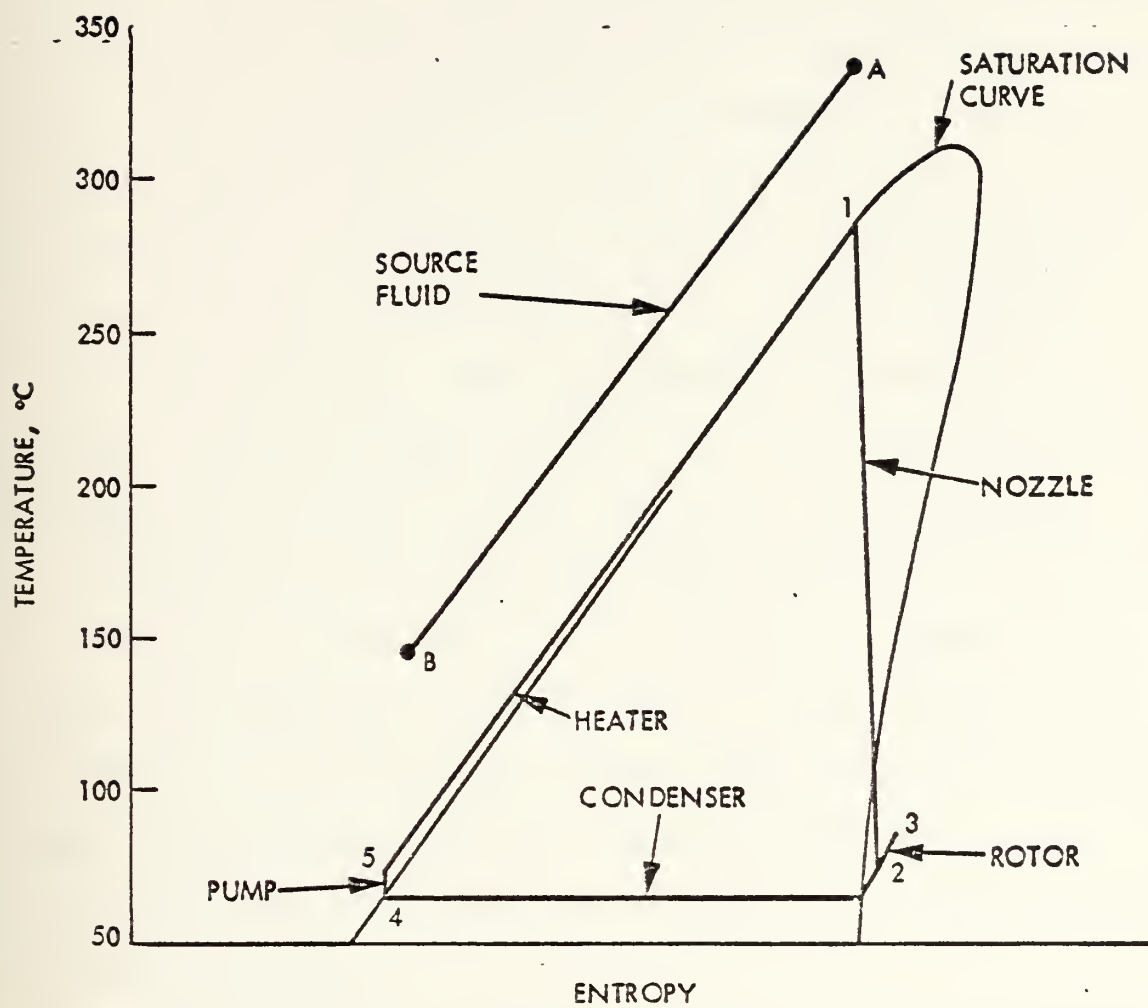


Figure 8. Wet-to-Dry T-S Diagram

in a small turbine engine. For example a steam turbine of 150-kw shaft horsepower using the temperature given in Figure 2 would have a speed of about 60,000 rpm. A comparable two-phase turbine would operate at approximately 10,000 rpm. There is also an efficiency advantage. At temperature corresponding to Figure 2, a steam Rankine cycle would have an efficiency of approximately 28% where-as the two-phase cycle would have an efficiency of 37%. This is assuming equal turbine efficiencies. The two-phase cycle also allows for control of turbine speed because the vapor/liquid mixture ratio can be varied to change the nozzle exit velocity. This is a capability unavailable in a conventional steam turbine.

Both of the dual-phase concepts can be thought of as a form of a regenerated Rankine cycle. The dual-phase cycle by control of liquid/vapor mixture ratio enhances the overall power system controllability. The T-S relationship for a dual-phase two-component engine cycle compared to a Rankine cycle is shown in Figure 9.

Two design studies References 1 and 2, have shown potential advantages in the two-phase engine cycle as compared to the conventional Rankine cycle for marine propulsion. The following advantages were noted:

1. High Efficiency - Full load output power performance gains ranging from 20 to 50 percent was found.
2. Direct Drive - Direct drive at speeds ranging from 90-4500 rpm was found possible with a single-stage turbine.

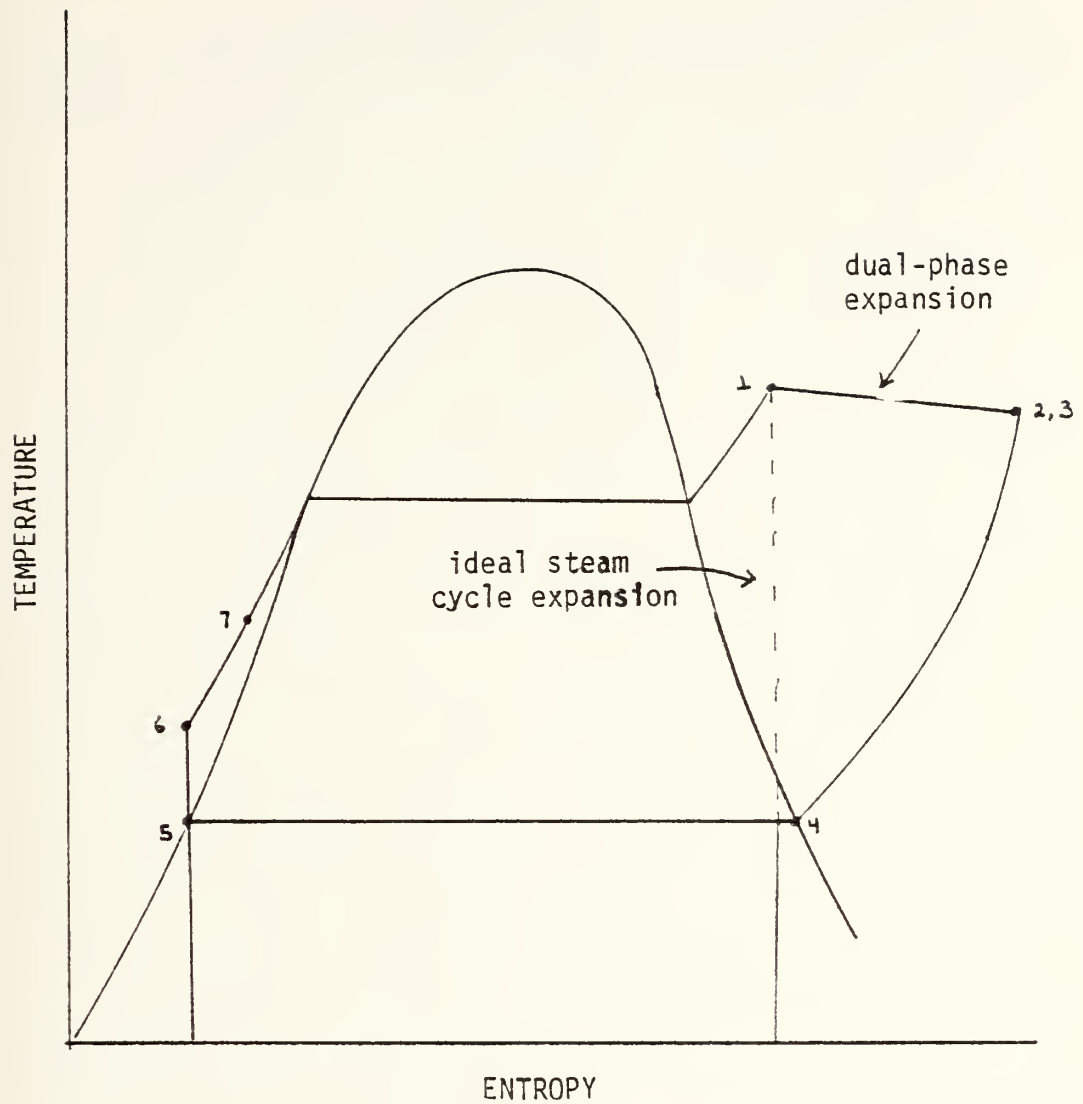


Figure 9. T-S Comparison of Dual-Phase Two-Component Cycle & Rankine Cycle

3. Reduced Volume - Volume reduction of 30 percent were estimated.

4. High Part-Load Efficiency - Variable mass ratio enabled part-load (cruise) efficiency gain of as much as 100 percent.

II. DUAL-PHASE NOZZLE THEORY

The flow phenomenon of a two-phase mixture has been analyzed in Reference 1. It is repeated as follows. The problem is illustrated in Figure 10. A spatially uniform two-component mixture of liquid drops and gas enters a nozzle at high pressure and low velocity and expands to low pressure and high velocity. The objective of the analysis is to determine, for a specified pressure the drop diameter D and the temperatures T_g and T_L , velocities V_g and V_L and flow rates \dot{m}_g and \dot{m}_L of the gas and liquid phases, respectively, at each station in the nozzle given the initial values of D , T_g , T_L , V_g , V_L , the total flow rate, and the properties of the fluids.

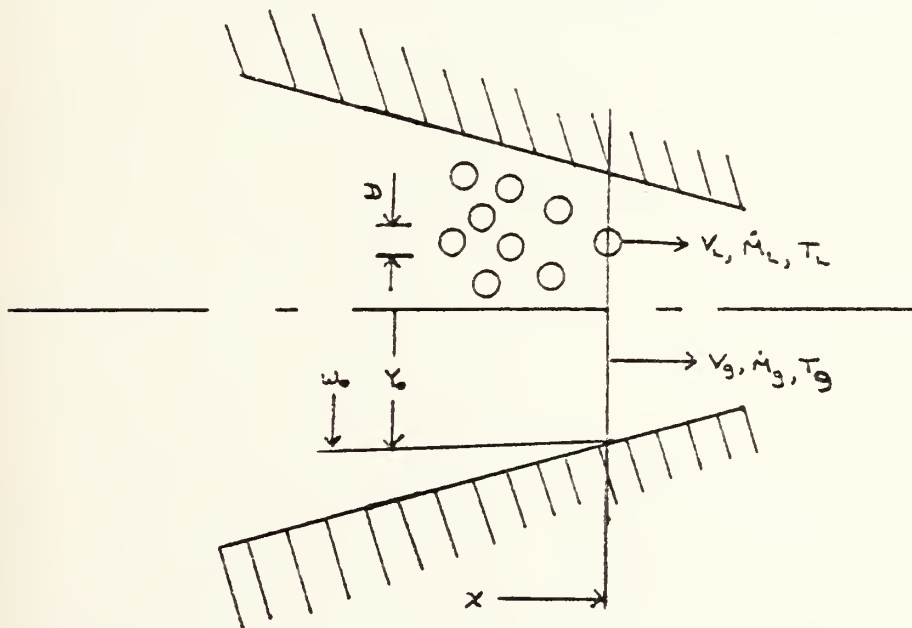


Figure 10. Dual-Phase Nozzle Flow
Geometry & Nomenclature

The five relations employed to compute the five unknowns D , T_g , T_L , V_g , and V_L , are (1) the momentum equation for the mixture, (2) the energy equation for the mixture, (3) the drop drag equation, (4) the drop heat transfer equation, and (5) the drop breakup criterion. Solubility and vapor pressure relations provide the flow rate ratio \dot{m}_g/\dot{m}_L .

A. ASSUMPTIONS

The assumptions employed in the two-component analysis are as follows:

1. The liquid is uniformly dispersed as spherical drops all of the same diameter.
2. The drops break up to limit the Weber number to 6.
3. There are no external forces acting on the two-phase mixture other than pressure and wall shear, and there is no heat transfer to or from the mixture.
4. The flow is one-dimensional.
5. The drops are large enough for the surface curvature to have negligible effect on the vapor pressure of the liquid and for the surface energy to be negligible.
6. The drops are isothermal.
7. The gas mixture obeys the additive-pressure law.
8. The partial pressure of the predominantly liquid component in the liquid is given by Raoult's Law.
9. The concentration of the predominantly gaseous component in the liquid is given by Henry's Law.

10. The volume of the liquid solution is equal to the sum of the volumes of the pure liquids.

Assumption 1 restricts the analysis to nozzles having spatially uniform injection of the liquid into the gas and operating at gas-to-liquid volume ratios greater than unity. Assumption 2, the drop breakup criterion, states that drop diameter is limited to a value D for which $W_e = \rho_g V_g^2 D / 2\sigma = 6$. Thus

$$D_{max} = \frac{12\sigma}{\rho_g V_g^2} \quad (1)$$

where ρ_g is the gas density, V_g is the slip velocity $V_g - V_L$, and σ is the liquid surface tension. The form of Eq. (1) is physically reasonable in that the Weber number is proportional to the ratio of stagnation pressure $\rho_g V_g^2 / 2$ to surface tension pressure $4\sigma/D$. Hence, a drop would be expected to flatten and breakup at a sufficiently high value of W_e . This has been verified experimentally and the critical Weber number found to be 6, within a factor of about two. An additional restriction is that for actual breakup to occur, the time spent at a Weber number exceeding 6 must be longer than the natural period of oscillation of the drop, $\pi(\rho_L D^3 / 3)^{1/2} / 4$, where ρ_L is the density of the liquid. This requirement is met only in two-phase nozzles longer than about 10 in. and Assumption 2 may cause the analysis to overestimate the exit velocity by increasing amounts as the nozzle length decreases below 10 in.

Assumption 3 excludes magnetohydrodynamic and mechanical body forces. The exclusion of wall heat transfer is correct for the insulated nozzles of interest for power systems. In addition, the relatively high velocity results in short residence times in the nozzle proper.

Assumption 4 is closely met in practical nozzles since good performance requires small wall angles, large throat radius of curvature, and uniformly distributed injection of the fluids at the nozzle entrance.

Assumption 5 is valid for the drop sizes of 0.001 to 0.010 in. produced by the Eq. (1) breakup criterion. Assumption 6 is valid because of the rapid internal circulation in drops. Assumption 7 introduces negligible error in most cases of practical interest since the vapor pressure of the liquid is small and needs only to be evaluated approximately.

Assumptions 8, 9, and 10 are either valid, or cause little error, for fluids of low miscibility, which are the fluids of interest.

B. DERIVATION OF EQUATIONS FOR FREE-STREAM FLOW

1. Continuity

Referring to Figure 1, the nozzle flow area A is equal to the gas flow area $\dot{m}_g / \rho_g V_g$ plus the liquid flow area $\dot{m}_L / \rho_L V_L$. Thus

$$A = \dot{m}_g \left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_L V_L} \right) \quad (2)$$

where r is the mass mixture ratio \dot{m}_L / \dot{m}_g .

2. Momentum

By Assumption 3, the only force acting on the free-stream flow is that due to the pressure gradient. If \dot{M} is the momentum flux at flow area A, the change in momentum flux across pressure increment dp is

$$d\dot{M} = -Adp \quad (3)$$

The momentum flux can be written as the sum of the momentum fluxes of the gas and liquid. Thus,

$$\dot{M} = \dot{m}_g V_g + \dot{m}_l V_l \quad (4)$$

If the flow were allowed to continue at constant pressure, V_g and V_l would become equal to each other at the mass-weighted mean velocity \bar{V} . Since for this process, $d\dot{M} = 0$, the value of \bar{V} is given by

$$(\dot{m}_g + \dot{m}_l)\bar{V} = \dot{m}_g V_g + \dot{m}_l V_l \quad (5)$$

or

$$\bar{V} = \frac{V_g + rV_l}{1+r} \quad (6)$$

Thus, the momentum flux can be written

$$\dot{M} = (\dot{m}_g + \dot{m}_l)\bar{V} \quad (7)$$

Since $\dot{m}_g + \dot{m}_l$ is constant, the change in momentum flux is

$$d\dot{M} = (\dot{m}_g + \dot{m}_l)d\bar{V} \quad (8)$$

Substituting Eqs. (8) and (2) into Eq. (3), $d\bar{V}$ can be written

$$d\bar{V} = -\frac{1}{1+r} \left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l} \right) dp \quad (9)$$

The slip ratio is defined as

$$s = V_s/\bar{V} = (V_s - V_L)/\bar{V} \quad (10)$$

This equation can be combined with Eq. (6) to give V_g and V_L in terms of \bar{V} :

$$V_s = \left(1 + \frac{rs}{1+r}\right) \bar{V} = a\bar{V} \quad (11)$$

$$V_L = \left(1 - \frac{s}{1+r}\right) \bar{V} = b\bar{V} \quad (12)$$

The gas density can be expressed as

$$\rho_g = W_g p / RT_g \quad (13)$$

where W_g is the effective molecular weight of the gas mixture and R is the universal gas constant. Eq. (13) is the definition of the effective molecular weight W_g , which is the quantity that gives the actual gas density when substituted in Eq. (13).

Substituting Eqs. (11) - (13) into Eq. (9), the differential momentum equation is

$$2\bar{V}d\bar{V} = d\bar{V}^2 = -\frac{2}{1+r} \left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_L} \right) dp \quad (14)$$

The quantities a and b are slowly varying because s is typically only 0.1 to 0.3 and slowly varying. The quantities r , T_g , W_g and ρ_L are also slowly varying. Integrating

Eq. (14) over a pressure increment Δp , for which a , b , r , T_g , W_g , and ρ_L are constant to within the desired accuracy, the change in \bar{V}^2 is

$$\Delta \bar{V}^2 = - \frac{2}{1+r_m} \left(\frac{RT_{g_m}}{a_m W_{g_m}} \log_e \frac{p + \Delta p/2}{p - \Delta p/2} + \frac{r_m \Delta p}{b_m \rho_{l_m}} \right) \quad (15)$$

All quantities other than pressure can be taken outside the integral and evaluated at their mean values (denoted by subscript m) corresponding to the mid-interval pressure p . Thus,

$$\begin{aligned} \Delta \bar{V}^2 = & - \frac{2}{1+r_m} \\ & \times \left(\frac{RT_{g_m}}{a_m W_{g_m}} \int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} \frac{dp}{p} + \frac{r_m}{b_m \rho_{l_m}} \int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} dp \right) \end{aligned} \quad (16)$$

Performing the integrations,

$$\Delta \bar{V}^2 = - \int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} \frac{2}{1+r} \left(\frac{RT_g}{a W_g p} + \frac{r}{b \rho_l} \right) dp \quad (17)$$

Equation (17) is the final form of the momentum equation.

3. Energy

The enthalpy change of the mixture between state 1 (the beginning of pressure interval Δp) and state 2 (the end

of the interval) can be evaluated in two steps: (1) phase change at ρ_1, T_{g1}, T_{L1} and (2) change to ρ_2, T_{g2}, T_{L2} , at fixed composition.

The enthalpy change for step 1 is

ΔH_1	=	amount of A vaporized	X	enthalpy required to vaporize and heat unit mass of A from T_L to T_{gL}
	+	amount of B vaporized	X	enthalpy required to vaporize and heat unit mass of B from T_{L1} to T_{g1}
	+	amount of A and B	X	kinetic energy required to accelerate unit mass from V_{L1} to V_{g1}

or

$$\begin{aligned} \Delta H_1 = & (\dot{m}_{a_{g2}} - \dot{m}_{a_{g1}}) [L_{a1} + c_{a_{g1}} (T_{g1} - T_{L1})] \\ & + (\dot{m}_{b_{g2}} - \dot{m}_{b_{g1}}) [L_{b1} + c_{b_{g1}} (T_{g1} - T_{L1})] \\ & + (\dot{m}_{g2} - \dot{m}_{g1}) (V_{g1}^2 - V_{L1}^2) / 2 \end{aligned} \quad (18)$$

where L and c are latent heat and specific heat, respectively.

Introducing more compact notation.

$$\begin{aligned} \Delta H_1 = & \Delta \dot{m}_g (L_{a1} + c_{a_{g1}} \delta_1 T) \\ & + \Delta \dot{m}_b (L_{b1} + c_{b_{g1}} \delta_1 T) + \frac{\Delta \dot{m}_g \delta_1 V^2}{2} \end{aligned} \quad (19)$$

The enthalpy change for step 2 is evaluated from the temperature, pressure, and velocity changes, with properties evaluated at mean T and ρ for the interval.

$$\begin{aligned}
\Delta H_2 &= \dot{m}_{g_2} [c_{g_m}(T_{g_2} - T_{g_1}) + \frac{1}{2} (V_{g_2}^2 - V_{g_1}^2)] \\
&\quad + \dot{m}_{l_2} [c_{l_m}(T_{l_2} - T_{l_1}) + \frac{p_2 - p_1}{\rho_{l_m}} \\
&\quad + \frac{1}{2} (V_{l_2}^2 - V_{l_1}^2)]
\end{aligned} \tag{20}$$

$$\begin{aligned}
&= \dot{m}_{g_2} \left(c_{g_m} \Delta T_g + \frac{\Delta V_{g_2}^2}{2} \right) \\
&\quad + \dot{m}_{l_2} \left(c_{l_m} \Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_{l_2}^2}{2} \right)
\end{aligned} \tag{21}$$

By Assumption 3, no work is done by the free-stream flow and no heat is transferred to it. Hence,

$$\Delta H_1 + \Delta H_2 = 0 \tag{22}$$

Substituting Eqs. (19) and (21) into Eq. (22) and solving for ΔT_g gives the energy equation for the mixture:

$$\begin{aligned}
\Delta T_g &= - \frac{1}{c_{g_m}} \left[\frac{\Delta V_{g_2}^2}{2} + r_2 \left(c_{l_m} \Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_{l_2}^2}{2} \right) \right. \\
&\quad + \frac{\Delta \dot{m}_{g_1} \delta_1 V^2}{2 \dot{m}_{g_2}} + \frac{\Delta \dot{m}_{a_2}}{\dot{m}_{g_2}} \left(L_{a_1} + c_{a_{g_1}} \delta_1 T \right) \\
&\quad \left. + \frac{\Delta \dot{m}_{b_2}}{\dot{m}_{g_2}} \left(L_{b_1} + c_{b_{g_1}} \delta_1 T \right) \right]
\end{aligned} \tag{23}$$

4. Drag

Although no force other than pressure acts on the free-stream flow as a whole, a drag force exists between

the phases. Hence, a second momentum equation must be written using as the control volume the boundary between the phases.

The two forces acting on each liquid drop are the buoyancy due to the pressure gradient and the drag due to the relative gas velocity. The sum of these is equal to the mass times the acceleration of the drop. Thus, for a single drop.

$$\begin{array}{rclclcl} \text{dynamic pressure of} & & \text{drag} & & \text{frontal area} \\ \text{relative gas flow} & \times & \text{coefficient} & \times & \text{of drop} \\ \\ - & \text{volume} & \times & \text{pressure} & = & \text{mass} & \times & \text{acceleration} \\ & \text{of drop} & & \text{gradient} & & \text{drop} & & \text{of drop} \end{array}$$

or

$$\begin{aligned} \left(\frac{1}{2} \rho_s |V_s| V_s \right) C_D \frac{\pi D^2}{4} - \frac{\pi D^3}{6} \frac{dp}{dx} \\ = \left(\frac{\pi D^3}{6} \rho_l \right) \left(V_l \frac{dV_l}{dx} \right) \end{aligned} \quad (24)$$

The absolute value sign in the first term makes the drag force positive when $V_g > V_L$ and negative when $V_g < V_L$.

Solving Eq. (24) for dV_L ,

$$dV_l = \frac{3\rho_s |s| s \bar{V}^2 C_D dx}{4\rho_l V_l D} - \frac{dp}{\rho_l V_l} \quad (25)$$

Differentiating Eq. (12), dV_L can also be expressed in terms of s , r , and \bar{V} . Thus,

$$dV_L = b d\bar{V} + \bar{V} \left[\frac{s dr}{(1+r)^2} - \frac{ds}{1+r} \right] \quad (26)$$

Solving for ds ,

$$ds = \frac{b(1+r) d\bar{V}}{\bar{V}} + \frac{s dr}{1+r} - \frac{(1+r) dV_L}{\bar{V}} \quad (27)$$

Substituting dV_L from Eq. (25), noting that $d\bar{V} = d\bar{V}^2/2\bar{V}$, using Eq. (12), and writing for a finite increment, results in,

$$\begin{aligned} \Delta s = & \frac{b_m(1+r_m) \Delta \bar{V}^2}{2\bar{V}_m^2} + \frac{(1+r_m) \Delta p}{b_m \rho_{l_m} \bar{V}_m^2} + \frac{s_m \Delta r}{1+r_m} \\ & - \frac{3\rho_{s_m} |s_m| s_m C_{D_m} (1+r_m) \Delta x}{4 b_m \rho_{l_m} D} \end{aligned} \quad (28)$$

This is the drag equation employed when x is specified as a function of p .

Solving Eq. (28) for Δx yields the required alternative equation:

$$\begin{aligned} \Delta x = & \frac{4D}{3\rho_{s_m} |s_m| s_m C_{D_m} \bar{V}_m^2} \left[\Delta p + \frac{b_m^2 \rho_{l_m} \Delta \bar{V}^2}{2} \right. \\ & \left. + \frac{b_m \rho_{l_m} \bar{V}_m^2}{1+r_m} \left(\frac{s_m \Delta r}{1+r_m} - \Delta s \right) \right] \end{aligned} \quad (29)$$

5. Heat Transfer

Although no heat is transferred to the mixture as a whole, heat transfer exists between the phases. Hence, a second energy equation must be written using as the control volume the boundary between the phases.

The work dW done on the liquid is that due to drag by the gas. (Only work done by shear or shaft forces is included in dW when writing the First Law for a control volume). Multiplying Eq. (24) by the number flow rate of drops $\dot{N} = 6\dot{m}_L/\pi D^3 \rho_L$, the drag force F_d on that quantity of liquid is

$$F_d = \frac{\dot{N}}{8} \rho_g |V_r| V_r C_D \pi D^2 = \frac{\dot{m}_l}{\rho_l} \frac{dp}{dx} + \dot{m}_l V_l \frac{dV_l}{dx} \quad (30)$$

The work done on the liquid is

$$-dW = F_d dx = \dot{m}_l \left(\frac{dp}{\rho_l} + \frac{dV_l^2}{2} \right) \quad (31)$$

The heat dQ transferred from the liquid is made up of two parts: (1) the convective cooling due to the temperature difference between the liquid and gas and (2) the evaporative cooling due to the latent heat supplied to the liquid vaporized. The convective cooling is

$$-dQ_c = h A_s \dot{N} (T_l - T_g) dt \quad (32)$$

where h is the heat-transfer coefficient, $A_d = \pi D^2$ is the surface area of a drop, and $dt = dx/V_L$ is the time required to traverse dx . Thus,

$$-dQ_e = \frac{6h\dot{m}_l(T_g - T_l)dx}{D\rho_l V_l} \quad (33)$$

The evaporative cooling is

$$-dQ_v = L_a d\dot{m}_a + L_b d\dot{m}_b, \quad (34)$$

The change in enthalpy of the liquid over the pressure increment dp is

$$dH = \dot{m}_l \left(c_l dT_l + \frac{dp}{\rho_l} + \frac{dV_l^2}{2} \right) \quad (35)$$

Substituting Eqs. (31), (33), (34), and (35) into the steady-flow energy equation $dQ - dW = dH$, the result is

$$\frac{6h\dot{m}_l \delta T dx}{D\rho_l V_l} - L_a d\dot{m}_a - L_b d\dot{m}_b = \dot{m}_l c_l dT_l \quad (36)$$

where $\delta T = T_g - T_L$.

Writing for a finite interval, the final form of the drop heat-transfer equation is

$$\Delta T_l = \frac{1}{c_{l_m}} \left[\frac{6h\delta_m T \Delta x}{D\rho_{l_m} V_{l_m}} - L_{a_m} \frac{\Delta \dot{m}_a}{\dot{m}_{l_m}} - L_{b_m} \frac{\Delta \dot{m}_b}{\dot{m}_{l_m}} \right] \quad (37)$$

Equations (1), (17), (23), (23), and (37) are the five equations that must be solved simultaneously to obtain the values of the five dependent variables D , T_g , T_L , V_g , and V_L as a function of the independent variable p . To carry out the solution all quantities in the equations must be expressed in terms of these six variables.

C. WALL SHEAR AND BOUNDARY LAYER

For a two-phase nozzle, the momentum flux of the frictionless nozzle flow is that given by

$$\dot{M} = \dot{m}_t \bar{V}$$

The mean mixture density corresponding to the mean velocity \bar{V} is

$$\rho' = \frac{\dot{m}_t}{A\bar{V}} = \frac{\rho_l}{1 + r_a} \quad (38)$$

where r_a is the ratio of gas flow area to liquid flow area $\rho_l V_l / \rho_g V_g$.

From the definition of the momentum thickness, the value of θ at a station where the nozzle wall radius is y_0 is given by

$$\dot{M} - \dot{M}_f = 2\pi y_0 \theta \frac{\dot{m}_t \bar{V}}{A} = 2\pi y_0 \rho' \bar{V}^2 \theta \quad (39)$$

where \dot{M}_f is the momentum flux of the real flow with friction.

The skin-friction coefficient can be defined using the same quantities as single-phase flow

$$C_f = \frac{2\tau_w}{\rho' \bar{V}^2} \quad (40)$$

where τ_w is the wall shear. It will be shown that a valid C_f value can be provided.

The boundary-layer momentum equation then becomes

$$d\theta = \frac{C_f}{2} dx - \theta \left[\frac{1 + (\delta^*/\theta)}{\bar{V}} d\bar{V} + \frac{1}{\rho' \bar{V}} d(\rho' \bar{V}) + \frac{1}{R_w} dR_w \right] \quad (41)$$

where δ^* is the displacement thickness, i.e., the distance the wall must be moved outward to give the same flow rate as with frictionless flow.

Assuming a $\frac{1}{2}$ power velocity profile and no density variation, the shape factor δ^*/θ is obtained from

$$\frac{\delta^*}{\theta} = \frac{\int_0^\delta [1 - (y/\delta)^{1/2}] dy}{\int_0^\delta (y/\delta)^{1/2} [1 - (y/\delta)^{1/2}] dy} = \frac{9}{7}$$

where δ is the velocity thickness of the boundary layer.

Noting that $d\bar{V}$ can be written $d\bar{V}^2/2\bar{V}$, and that $d(\rho' \bar{V}) = d(m_t/A)$, the finite-difference form of Eq. (41) is

$$\Delta\theta = \frac{C_{f_m}}{2} \Delta x - \theta_m \left(\frac{8}{7\bar{V}_m^2} \Delta\bar{V}^2 - \frac{1}{A_m} \Delta A + \frac{1}{y_{om}} \Delta y_o \right)$$

Wall shear in homogeneous two-phase flow has been found to be equal to that which would exist with pure liquid at equal velocity and boundary-layer thickness, multiplied by the wetted wall fraction:

$$\tau_w = \frac{C_{f_l}}{2} \rho_l V_l^2 \frac{A_l}{A} = \frac{C_{f_l} \rho_l V_l^2}{2(1 + r_a)} \quad (42)$$

where C_{f_l} is the skin friction coefficient for liquid at a Reynolds number of

$$R_\delta = \frac{\rho_l V_l \delta}{\mu_l}$$

For a 1/7-power profile, the velocity thickness,

$$\delta = \frac{72}{7} \theta$$

A convenient relation for C_{f_l} as a function of R_δ is the Shultz-Grunow relation which can be written

$$C_{f_l} = \frac{0.208}{(\log_{10} R_\delta + 0.425)^{2.584}}$$

Comparison of Eqs. (40) and (42) shows that C_f can be written

$$C_f = \frac{rb}{1+r} C_{f_l}$$

Thus, the final form of the boundary-layer momentum equation is

$$\Delta\theta = \frac{r_m b_m}{1+r_m} \frac{C_{f_l} \Delta x}{2} - \theta_m \left(\frac{8\Delta\bar{V}^2}{7\bar{V}_m^2} - \frac{\Delta A}{A_m} + \frac{\Delta y_o}{y_{om}} \right)$$

Let \bar{V}_δ be the mean velocity of the flow including the boundary layer. Then, from Eq. (39),

$$\dot{m}_t \bar{V}_\delta = \dot{M}_f = \dot{m}_t \bar{V} - 2\pi y_o \rho \bar{V}^2 \theta$$

Hence, employing Eq. (38), the mean exit velocity including the boundary layer is

$$\bar{V}_\delta = \bar{V} \left(1 - \frac{2\pi y_o \theta}{A} \right)$$

By the definition of the displacement thickness, the flow rate is reduced by the throat displacement thickness δ_t^* to

$$\dot{m}_\delta = \dot{m}_t \left(1 - \frac{2\delta_t^*}{y_{ot}} \right)$$

D. NOZZLE THEORY SUMMARY

The preceding equations form the basis for the mathematical model which is used to predict, based on inlet conditions, the exit velocity, and temperature of the mixture. These equations also form the basis for the model which provides the optimum nozzle shape given a set of inlet conditions. Some additional relationships are, however, required. These are:

1. Phase properties - to establish the mass ratio, mass flow rate ratio of gas to liquid, and the thermal conductivity of the mixture.

2. Liquid drop drag coefficients.
3. The liquid drop heat transfer coefficients.
4. Boundary layer momentum thickness and displacement thickness.
5. Skin friction coefficient.

These five additional relationships are developed in detail in Reference [1].

III. COMPUTER PROGRAM DUAL-PHASE NOZZLE

The computer program employed in this study is based on a program developed by Dr. G. Elliott of the Jet Propulsion Laboratory in Pasadena, California. The program was updated and converted for use on the Naval Postgraduate School computer. The Dual-Phase Two-Component program employs the theory in Section II. The program is written in Fortran computer language and can be compiled using a Watfiv or Fortran IV compiler.

This program has been utilized in dual-phase nozzle analysis and to provide values for comparison with the experimental results. To use the computer program the inlet conditions have to be specified. The flow conditions are: inlet pressure; mass ratio; inlet temperature of the gas and liquid; inlet velocity of the gas and liquid; total mass flow rate; and nozzle exit pressure. Section III B, shows specified details for data input.

There are two options that can be chosen. The first is prescribed pressure-versus-distance option MOP=0. The pressure profile $P(X)$ is selected corresponding to the adopted nozzle contour. If the pressure-versus-distance is used a $P(X)$ input table is required. This profile is developed from the actual measured pressure values in the experiments.

(See Appendix A for sample program.) The second option consist of an optimum nozzle contour option MOP=1. This option is useful only when the liquid drop diameter is constant.

The dual-phase two-component computer program is a structured program with thirteen subroutines controlled by a main program. This arrangement improved the programming process through better organization and programming notation.

The control point of the dual-phase two-component computer program is the "main section." It controls the flow path and operation of all input data, property tables, and calculations. It accomplishes this by calling the thirteen subroutines at the appropriate times, saving wanted data in files, and printing out desired information.

One of the most important subroutines which inputs information is the "INTRP" subroutines. INTRP controls the property table inputs. It reads in four two-dimensional tables and fourteen one-dimensional tables. These inputs are the properties of the gas and liquid phases of both components of the flow in the nozzle. The subroutine writes the values of these tables into a file and retrieves appropriate values from that file. INTRP can also interpolate for values used throughout the entire program.

Input of case data is controlled by subroutine "Sect 1." Identification information and case heading information is read and printed for each instance. Sect 1 also places the pressure vs. distance profile, if specified, in an array.

"Sect 2" through "Sect 6" are the subroutines which calculate the flow data. Sect 2 sets the initial conditions indicated in the input, and begins the iterations. Sect 3 computes initial flow rates of both components; the initial area of the nozzle; slip velocity; mean free stream velocity; and slip friction. Sect 4 computes the changes in flow parameters and new distances. It then begins to calculate new conditions such as flow rate, temperature, velocities, surface tension and mean area. Sect 5 is the binary cut convergence routine and computes mean boundary-layer parameters.

If a problem is diagnosed in any subroutines and "diagno" is called, it will print all output parameters calculated to that point. It also does the same if there is a convergence problem.

There are two subroutines that output calculated data, subroutine "Write" and subroutine "Output." Subroutine "Write" will send output information to the printer for a hard paper copy. Subroutine "Output" reads and stores the output on a file.

The two-phase two-component program has been written with comment statements in the text of the program. These will allow for a more understandable and, therefore, a more easily modified program. For specific details on the content of these subroutines, see Appendix M.

The dual-phase nozzle program was tested for correct output. Sample data and results were obtained from

Dr. David Elliott, were inputted into the program, and executed. The output was compared to the sample data. The program produced duplicate results.

The program begins by storing fluid property tables and reading in all input data. All nozzle inlet conditions are computed. The program then proceeds half a pressure step at a time. At the middle of each pressure interval, the changes in quantities across the interval are computed using the properties interpolated from the table for that pressure, and for the existing temperature. The change in slip is found if the pressure profile $P(X)$ is specified. At the end of each pressure step, the flow conditions are updated and initial conditions are determined for the next step. The dropsize is reduced at the point when the Weber number exceeds six. The flow conditions are printed if the pressure is one selected for output. The computation continues until the last pressure step has been completed and flow conditions at the smallest flow area encountered are printed as the throat conditions.

A. PROPERTY TABLES

1. Heat capacity of component "A" vapor in BTU/LBM-R is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for

this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 heat capacity (BTU/LBM-R)

25-36 pressure (psi)

37-48 heat capacity (BTU/LBM-R)

49-60 pressure (psi)

61-72 heat capacity (BTU/LBM-R)

The maximum entries of temperature are 35 values. For each value of temperature, the maximum number of entries of pressure and heat capacities are 35 values. Each row of this table will be terminated with the pressure and heat capacity equal to 10^5 . These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix B can be used to determine the values of heat capacities. The program structures its output in the format needed for the table input. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 heat capacity at .01 P

15-21 heat capacity at .4 Pa

22-28 heat capacity at .7 Pa

29-35 heat capacity at 1.0 Pa

34-42 heat capacity at 4.0 Pa

43-49 heat capacity at 7.0 Pa

50-56 heat capacity at 10.0 Pa

57-63 heat capacity at 40.0 Pa

64-70 heat capacity at 70.0 Pa

The temperature must be entered with
increasing value.

2. Heat capacity of component "B" gas, BTU/LBM-R is a function of temperature and pressure. This two-dimensional table has the same format as part A1 above.

3. Molecular weight of component "A" vapor is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for
this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 molecular weight

25-36 pressure (psi)

37-48 molecular weight

49-60 pressure (psi)

61-72 molecular weight

The maximum number entries of temperature are 35 values. For each value of temperature, the maximum entries of pressure and molecular weight are 35 values. Each row of this table will be terminated with the pressure and molecular weight equal to 10^5 . These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix C can be used to determine the values of molecular weight. The program formats its output in the format needed for the table input of the two-component two-phase computer program. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. The program used in Figure 8 can only be used with ideal gases. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 density at .01 P

15-21 density at .4 Pa

22-28 density at .7 Pa

29-35 density at 1.0 Pa

34-42 density at 4.0 Pa

43-49 density at 7.0 Pa

50-56 density at 10.1 Pa

57-63 density at 40.0 Pa

64-70 density at 70.0 Pa

The temperatures must be entered with
increasing value.

4. Molecular weight of component "B" gas is a function of temperature and pressure. This two-dimensional table has the same format as part A3 above.

5. There are fourteen one-dimensional tables. The one-dimensional tables are entered in the following format (for Z(T)):

Card 1: (format 6E12.6)

cols.

1-12 Ti-2, oR

13-24 Ti-2

25-36 Ti-1 $2 \leq i \leq 50$

37-48 Zi-01

49-60 Ti

61-72 Zi and Tj-1 < Tj for $2 \leq j \leq 50$

Each table is terminated by two consecutive entries of 10^5 , i.e., $T_k \equiv Z_k \equiv 10^5$ (1.0E5 right adjusted in the field).

The fourteen one-dimensional tables are (in order requested):

1. CAL(T) heat capacity of component A liquid,
BTU/LBM oR
2. CBL(T) heat capacity of component B liquid,
BTU/LBM oR
3. LA(T) latent heat of vaporization for com-
ponent A, BTU/LBM
4. LB(T) latent heat of vaporization for com-
ponent B, BTU/LBM
5. PBO(T) vapor pressure of component B
6. ROAL(T) density of liquid component A,
LBM/FT³
7. ROBL(T) density of liquid component B,
LBM/FT³
8. KAG(T) thermal conductivity of component
A gas, BTU/FT HR oR
9. KBG(T) thermal conductivity of component
B gas, BTU/FT HR oR

10. VIAL(T) viscosity of liquid component A,
LBM/FT HR
11. VIBL(T) viscosity of liquid component B,
LBM/FT HR
12. VIAG(T) viscosity of gas component A,
LBM/FT HR
13. VIBG(T) viscosity of gas component B,
LBM/FT HR
14. SIG(T) surface tension of liquid component
B, DYNE/CM

Appendix D gives sample property table for input.

B. CASE INPUT

A blank card must separate the property table from the data set decks following.

Card 1: (format 4A4, A2, 3A4, 7A4, A32, 2I6)
cols.

1-18 date

19-30 case number, may be any
alphanumeric data

31-60 identification

61-66 NS, number of pressure steps per
printout

(right justified integer).* Use -1 if new
property tables follows.

57-72 NP, number of printouts (right
justified)

Card 2: (All integers right justified in field)

(format 1116)

cols.

1-6 MBU, =0 constant droplet size, =1 drop
breakup

7-12 MOP, =0 X(P) table to be supplied, =1
X(P) is to be optimized

13-18 MGEO, =0 circular, =1 annular

19-24 NDS, maximum number of S iterations

25-30 NSO, maximum number of So iterations

31-36 NB, maximum number of TB iterations

37-42 NNS, first setting of step counter

Card 3: (format 5E12.6)

cols.

1-12 DP, pressure step size, negative for
decreasing, psi

13-24 RC, mass flow ratio

25-36 PHI, angle of annular nozzle axis, deg

37-48 RAXO, annular nozzle axis, in.

49-60 EMT, total flow rate *P final = $P_0 +$
 $(NS*NP - NNS - 1)*DP + DP_1$

Card 4: (format 6E12.6)

cols.

1-12 H, inverse Henry's Law constant, psi

13-24 ALAM, Lagrangian multiplier

25-26 DPL, first pressure step size
37-48 WAL, molecular weight of liquid a
49-60 WBL, molecular weight of liquid b
61-72 SA, Sutherland constant for component
A, oR

Card 5: (format 6E12.6)

cols.

1-12 SB, Sutherland constant for component
B, oR
13-24 DO, initial drop diameter, in.
25-36 PO, initial pressure, psia
37-48 TGO, initial gas temperature, oR
49-60 TLO, initial liquid tempeature, oR
61-72 VGO, initial gas velocity, FT/S

Card 6: (format 6E12.6)

cols.

1-12 VLO, Initial liquid velocity, FT/S
13-24 THOO, initial momentum thickness of
outer wall boundary layer, in.
25-36 THIO, initial momentum thickness of
inner wall boundary layer, in.
37-48 EDS, convergence criterion for S
49-60 ES0, convergence criterion for So
61-72 EB, convergence criterion for T, oR
If MOP=0, the following cards are present:
in 10 Card 7: (format 7A4, A2) cols.

1-30 X(P) table identification (and
alphanumeric data).

Card 8: (format 6E12.6)

cols.

1-12 pressure, pi-2, psia

13-24 distance, xi-2, in.

25-36 pressure, pi-1 $3 \leq i \leq 75$

37-48 distance, xi-1

49-60 pressure, pi

61-72 distance, xi

The last two entries are 1.0E5 and 1.0E5 right adjusted in their fields. The table must be monotonic increasing or decreasing. New property tables may be used by putting -1 in cols. 61-66 of Card 1, and following this with new property tables and data sets. Appendix E is a sample input data.

C. OUTPUT

For each case, the case identification is printed followed by the input parameters. If MOP=0, the X(P) table forms a part of this output. The following output then appears.

1. X distance, in.
2. P pressure, psia
3. R mass flow ratio
4. vb mean free-stream velocity, ft/s
5. a flow area, in. 2

6. t_b	gas temperature, or
7. t_l	liquid temperature, or
8. v_g	gas velocity, ft/s
9. v_l	liquid velocity, ft/s
10. v_s	slip velocity $v_g - v_l$, ft/s
11. s	slip fraction v_s/v_b
12. d	drop diameter, in.
13. r_v	ratio of gas volume flow to liquid volume flow
14. r_a	ratio of gas flow area to liquid flow area
15. α	mass fraction of component a dissolved in liquid
16. β	mass fraction of component b vapor in gas
17. \dot{m}_g	gas flow rate, lbm/s
18. \dot{m}_l	liquid flow rate, lbm/s
19. ρ_g	gas density, lbm/ft ³
20. ρ_l	liquid density, lbm/ft ³
21. w_{ag}	molecular weight of component a gas
22. w_{bg}	molecular weight of component b gas
23. w_g	mean molecular weight of gas
24. p_a	partial pressure of component a, psia
25. p_b	partial pressure of component b, psia
26. h_a	latent heat of vaporization of component a, btu/lbm
27. h_b	latent heat of vaporization of component b, btu/lbm

28. sigma liquid surface tension, dyne/cm
29. cgm specific heat of gas (at midpoint of pressure step), btu/lbm of
30. clm specific heat of liquid, btu/lbm of
31. vigm viscosity of liquid, lbm/ft hr
32. vilm viscosity of gas, lbm/ft hr
33. kgm thermal conductivity of gas, btu/hr ft of
34. rem reynolds number of flow over drops
35. cdm drag coefficient of drops
36. hm heat transfer coefficient of drops, btu/hr ft²
37. rb mass flow ratio after velocity and temperature equalization
38. ab flow area after equalization, in. ²
39. tb temperature after equalization, or
40. rvb volume flow ratio after equalization
41. alphb alpha after equalization
42. betab beta after equalization
43. mgb gas flow rate after equalization, lbm/s
44. mlb liquid flow rate after equalization, lbm/s
45. vilb liquid viscosity after equalization, lbm/ft hr
46. rogb gas density after equalization, lbm/ft³
47. rolb liquid density after equalization, lbm/ft³
48. wagb molecular weight of component a gas after equalization

49. wbgb molecular weight of component b gas after
 equalization
50. wgb mean molecular weight of gas after equalization
51. pab partial pressure of component a gas after
 equalization, psia
52. pbb partial pressure of component b gas after
 equalization, psia
53. g separator friction parameter
54. ref separator film reynolds number
55. yo distance from nozzle axis to outer wall, in.
56. wom angle of outer wall relative to axis, deg
57. tho momentum thickness of outer boundary layer, in.
58. delo velocity thickness of outer boundary layer, in.
59. delso displacement thickness of outer boundary layer,
 in.
60. redom reynolds number of outer boundary layer
61. cfom skin friction coefficient of outer boundary
 layer
62. twom shear stress on outer wall, psi
63. vbd mean velocity including boundary layer, ft/s
64. wim angle of inner wall relative to axis, deg
65. thi momentum thickness of inner boundary layer, in.
66. deli velocity thickness of inner boundary layer, in.
67. delsi displacement thickness of inner boundary
 layer, in.

68. redim reynolds number of inner boundary layer
69. cfim skin friction coefficient of inner boundary
layer
70. twin shear stress on inner wall, psi
71. nna number of iterations required to optimize $X(P)$
72. nis number of iterations required to converge on
s or so
73. nib number of iterations required to converge on
tb

IV. EXPERIMENTAL SYSTEM

The experimental system can be grouped into three subsystems. These are:

- a) nozzle
- b) air supply system
- c) liquid injection system

Each subsystem is described in the following sections.

Figure 11 is an overall system schematic.

A. NOZZLE

The nozzle has a convergent-divergent flow passage. It is 12 inches long with a variable exit area. The exit area can be varied from .45313 square inches to .84375 square inches. The pivot point is located 1 inch above the throat. This causes the throat to vary when the exit is varied. Since the change in the throat is negligible, it will be considered to be constant. It has a throat area of .45 square inches. The inlet area is 1.625 square inches. The throat is located 4 inches from the inlet. The nozzle is constructed by sandwiching two 1/2 inch thick machined aluminum nozzle profile plates between 1/2 inch plexiglas plates (Fig. 12). The aluminum nozzle plates are located at the end of a 30 inch long entry section and are easily adjustable. Figure 13 shows a close up of the aluminum section of the nozzle.

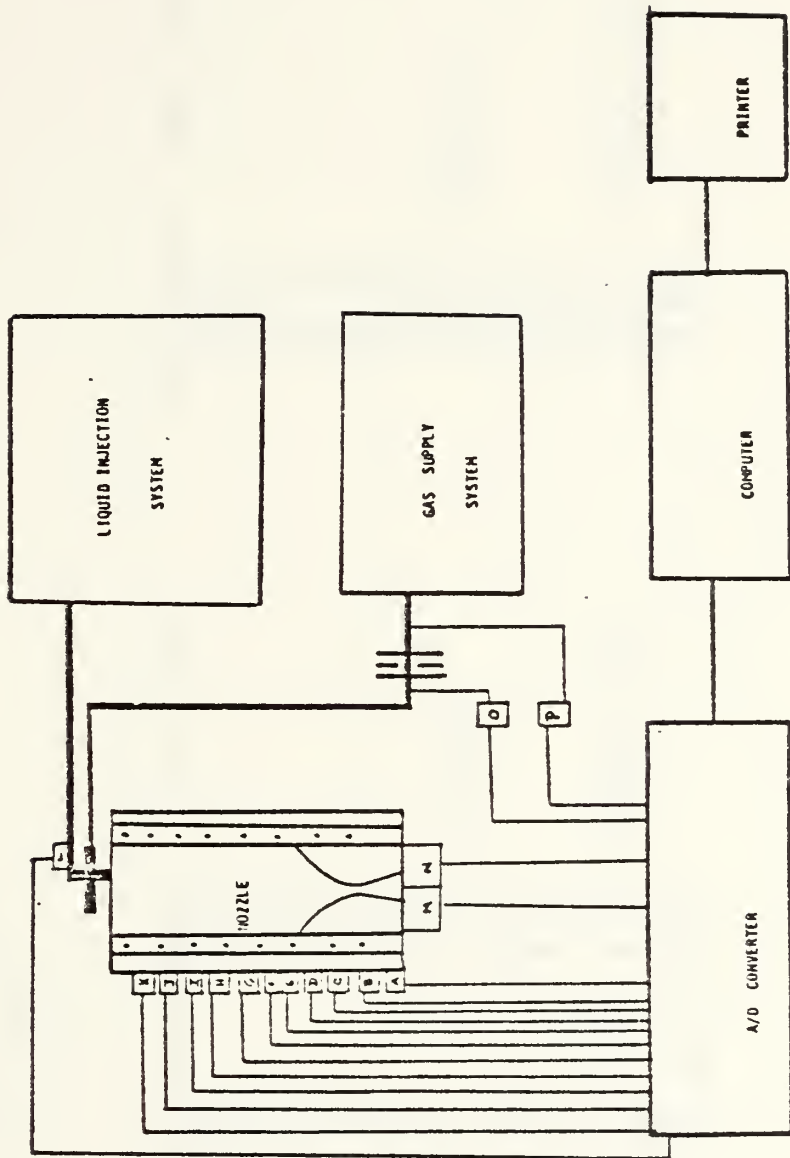


Figure 11. Experimental System Schematic

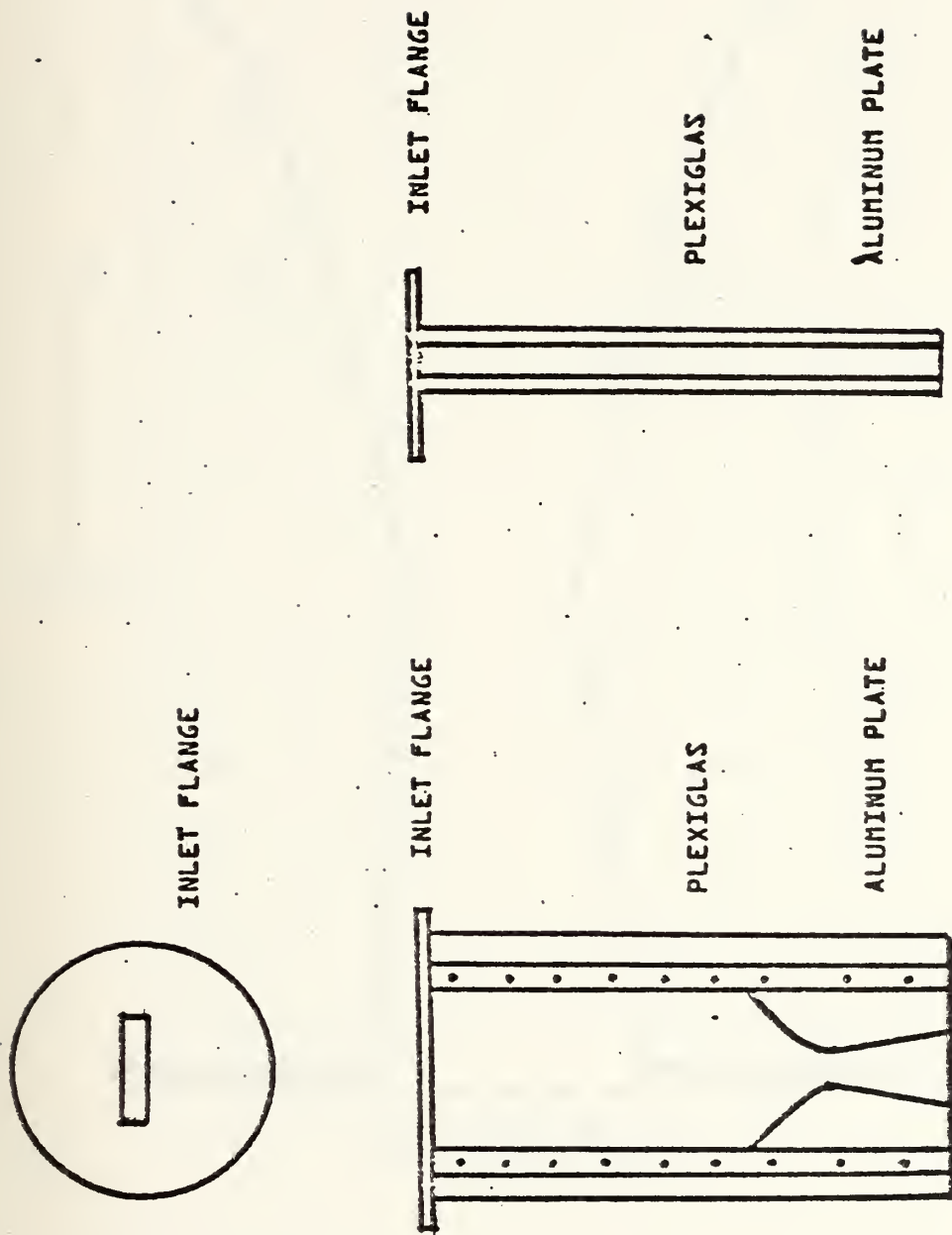


Figure 12. Nozzle Assembly Drawing

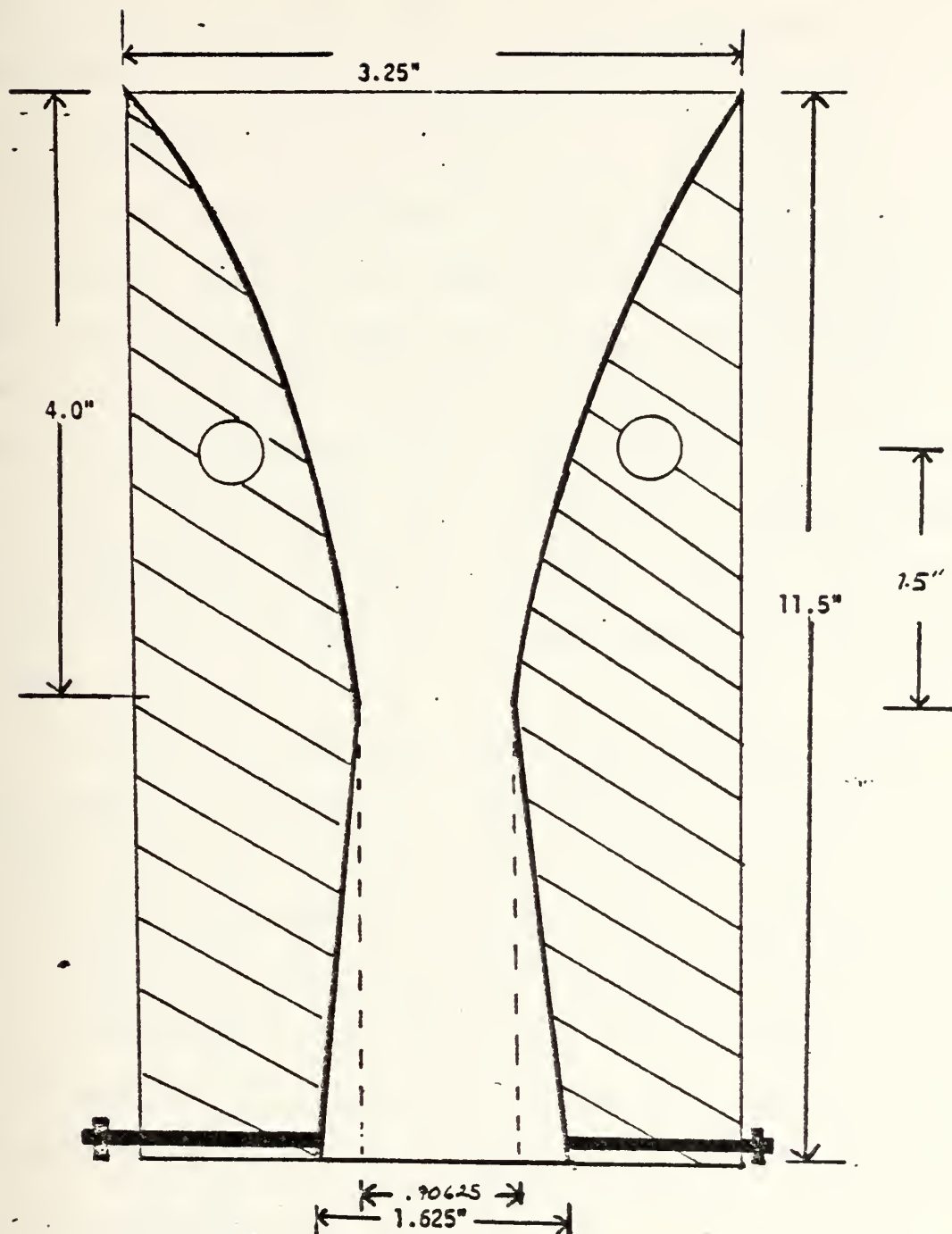


Figure 13. Nozzle Geometry Schematic

The inlet section provides the necessary space for pressure taps, liquid injection tubes, and other instrumentation and configuration options.

B. AIR SYSTEM

The air system is shown in Figure 14. Two 117 cubic feet tanks supplied with compressed air from an Ingersoll Rand two-stage air compressor provides the air storage volume required to support the nozzle's operation. Each storage tank has a pneumatically control Norgren gate valve at its exit. These valves are operated by a nitrogen actuator and controlled by a pressure regulator. The nitrogen is regulated to 40 psi control pressure which will open the Norgren valve.

The nozzle is supplied with air via a 3" i.d. pipe. The air supply to the nozzle is controlled by a solenoid actuated nitrogen operated 3 inch ball valve. The nitrogen is supplied via a regulator. By varying the nitrogen supply pressure to the ball valve, supply air pressure to the nozzle can be controlled. Air flow to the nozzle is measured with a standard ASME orifice plate. Figure 15 shows the dimensions of the orifice. The orifice is a model D-10512 with a 0.920 inch bore.

C. LIQUID INJECTION SYSTEM

The liquid injection system, Figure 16, is supplied by house water and is further pressurized by an Aurora electric

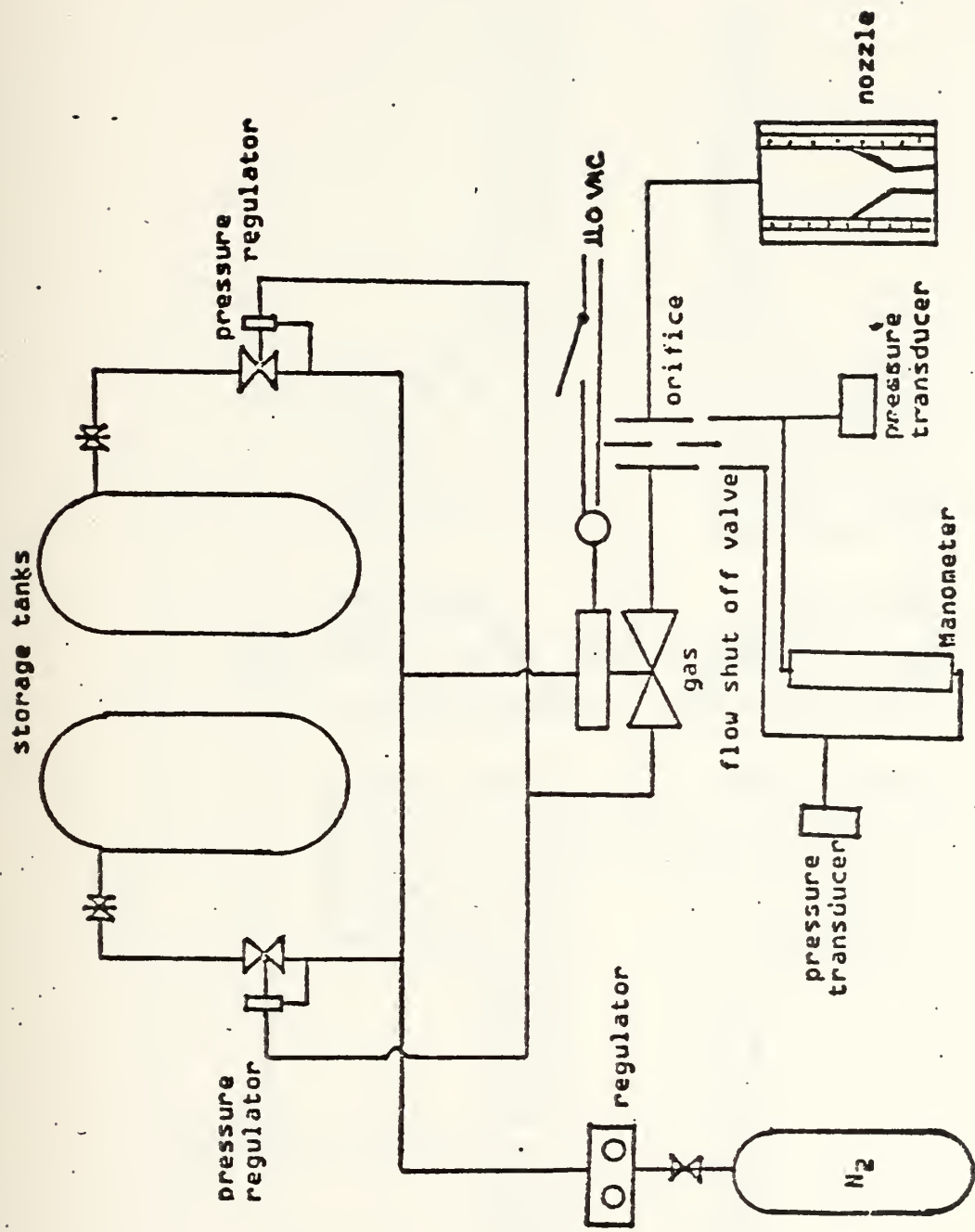


Figure 14. Orifice Schematic

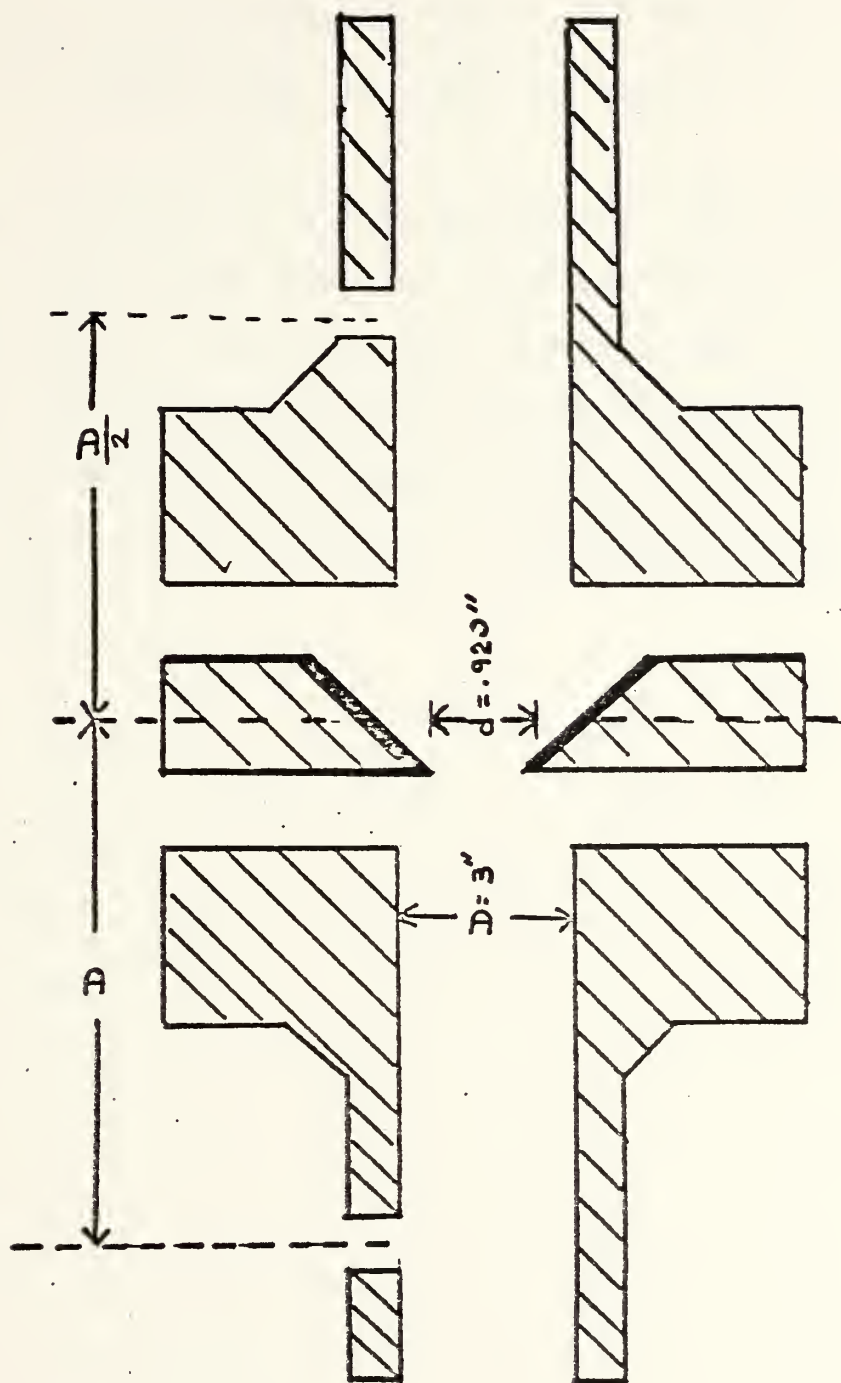


Figure 15. Air System Schematic

pump model/type 317696. The pump is rated at 50 gallons per min. The pump supplies pressurized water to the injection tube via two flowmeters (rotometers). The flowmeters are F&P co. precision bore flowrator tubes. One rotometer is rated at 1 to 12 gallons per min. and the other at .6 gallons per min.

The liquid injector is a 0.25 inch brass tube inserted in the 3" i.d. air supply pipe just upstream of the flange connection to the test section. The injector tube is drilled with sixteen 1/16th inch diameter holes facing the test section entrance. The drilled holes were made as small as possible consistent with achieving a significant liquid mass flow rate.

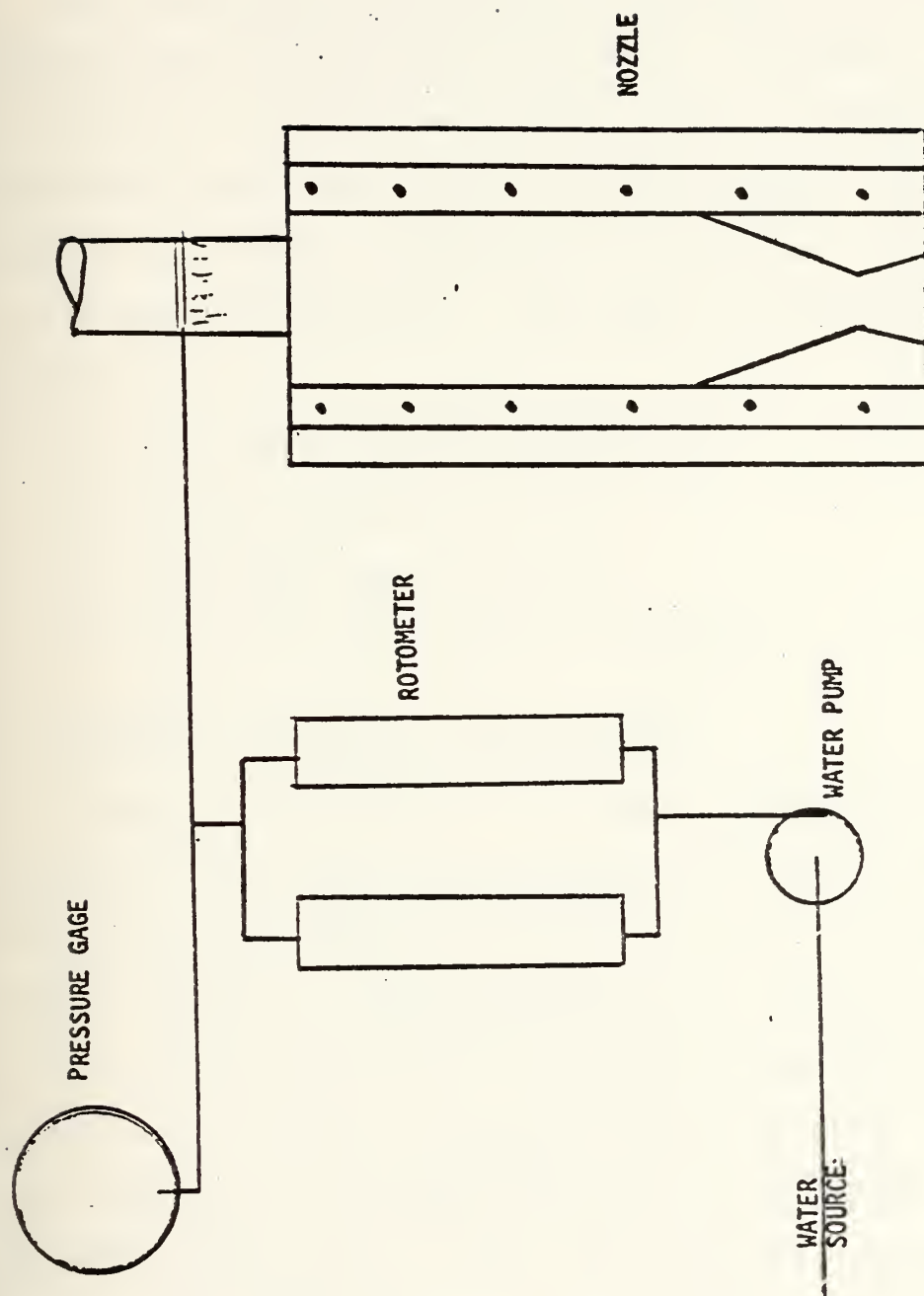


Figure 16. Liquid Injection System Schematic

V. INSTRUMENTATION SYSTEM

The instrumentation system is designed for automated data acquisition, analysis, and display. A schematic is depicted in Figure 17. Where ever possible, test operations and sequencing are under direct computer control. Each parameter measured involves an appropriate transducer, excitation source, and calibration procedure. The major instrumentation sub-systems are:

- (A) Pressure Measuring Transducers
- (B) Nozzle Thrust Force Block
- (C) Flow Measurement Devices
- (D) Data Acquisition/Control System

A. PRESSURE MEASURING TRANSDUCERS

Pressure measurements are made in fourteen locations throughout the experimental apparatus. Eleven Micro Switch 140PC pressure transducers model PK 87633 are placed on the nozzle assembly to measure pressure at various axial positions. Specifications for this model transducer are shown in Figure 18. The first pressure tap is located at one half inch from the inlet along the axis of the nozzle. The remainder are placed at one inch intervals toward the nozzle exit. These pressure taps are connected to the pressure transducers via a 1/4" o.d. plastic tubing. The

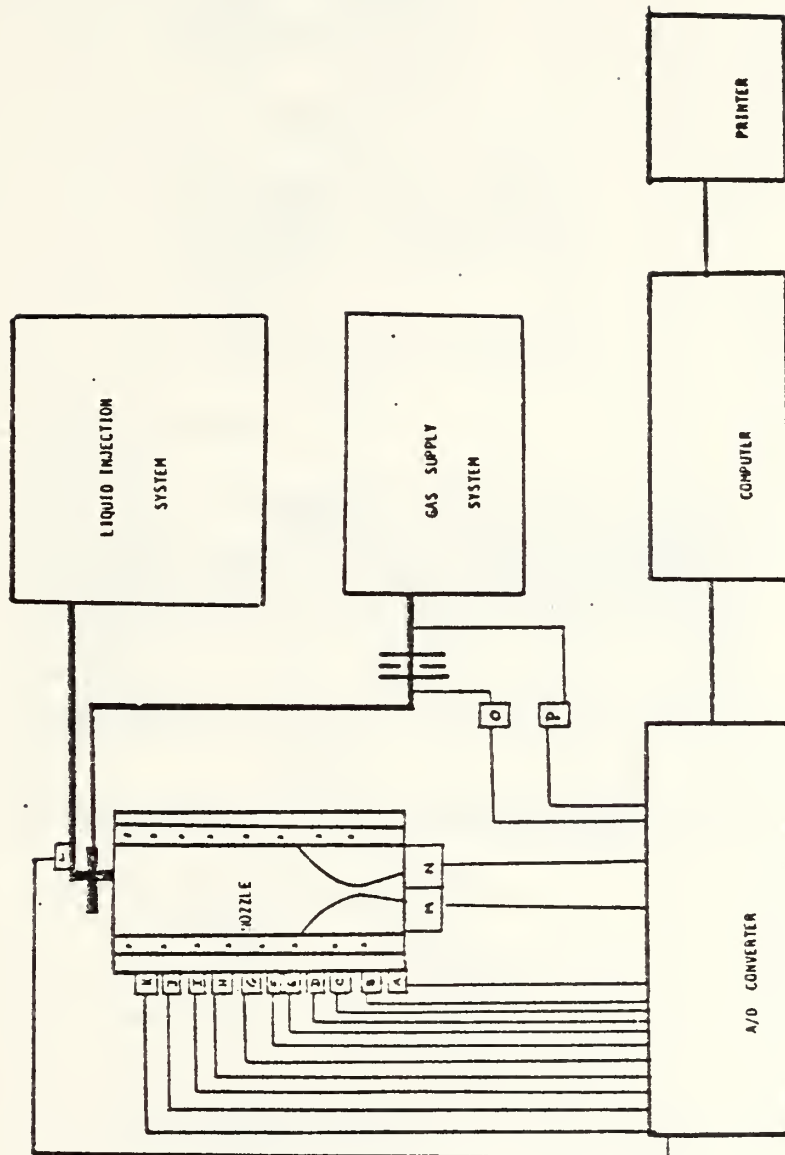


Figure 17. Instrumentation System Schematic

32.4
10.4

18.0
5.8

12.8
4.0

3.0
121

3.0
14

10.0
10

18.5
75

3.0
10

1.0
10

5.1
121

5.0
20

MICRO
SWITCH
VSA

TERMINALS IN THIS POSITION
ON OPPOSITE SIDE

INPUT PORT

OUTPUT
GROUND
SUPPLY

ALL LISTINGS

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.85	5.00	5.15	Volts
Null Offset	All	0.95	1.00	1.05	Volts
Excitation	All	8.00		20.0	VDC
Output Current Source Sink	All	10.0 5.0			mA
Supply Current (10K ohm load)	All		8.0		mA
Overpressure	0-1 0-5 0-15 0-15/0-30(L)			20 20 45 60	psi
Operating Temperature	-55°C to +125°C (-65°F to +257°F)				

Current Source

DC 20V

PRESSURE INPUT

SUPPLY

OUT

GND

R_L

Current Sink

DC 20V

PRESSURE INPUT

SUPPLY

OUT

GND

R_L

WARNING: Damage may result from reversal of supply and ground connections.

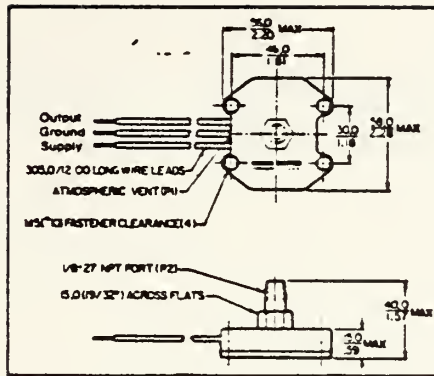
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pressure transducers are mounted on the side panel of the nozzle. See Figure 19 for locations. Each transducer has an identification letter corresponding to its position. Table I is the ID code for the transducers.

At the nozzle inlet a Micro Switch 200PC pressure transducer model PK 87690 is placed in the inlet line to measure the dual-phase mixture inlet pressure. Specifications for this model transducers are shown in Figure 19. Gas supply pressure is measured using a 200PC pressure transducer located at the orifice outlet. This transducer is also used to help measure differential pressure across the orifice. Another 200PC transducer is placed at the inlet of the orifice. The data acquisition program calculates the orifice differential pressure and then the air mass rate using the output from the above two transducers.

The pressure transducers provide output voltage proportional to applied pressure. These operate from a single, positive supply voltage ranging from 8 to 20 VDC. The supply voltage was maintained at 15VDC.

Each pressure transducer sends back a signal proportional to the input pressure. The signal is converted in the A/D converter to a digital signal which can be read by the HP9826. The pressure transducers were calibrated using a known pressure source. Appendix F depicts a sample calibration program written for a HP9826 computer. This program reads ten



200PC SPECIFICATIONS at $8.0 \pm 0.01\text{VDC}$, 25°C (unless otherwise noted)

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.80	5.00	5.20	V
Null Offset	All	0.95	1.00	1.05	V
Proof Pressure ①	0-100			200	psi
	0-250			500	
Burst Pressure ②	0-100		800		psi
	0-250		1000		
Excitation	All	8.0		20.0	VDC
Output Current Source	All	10.0			mA
Sink		5.0			
Supply Current	All		5.0		mA
Operating Temperature	All	-55°C to $+125^\circ\text{C}$ $(-65^\circ\text{F}$ to $+257^\circ\text{F})$			

* F.S.O. is the algebraic difference between end points (null and full pressure outputs).

- ① Maximum pressure without damage
 ② Without housing envelope rupture.

ELECTRICAL AND PRESSURE CONNECTIONS

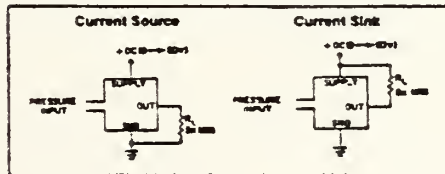


Figure 19. 200PC Pressure Transducer Specifications

Table I. ID Code for Instrumentation

<u>Letter Designation</u>	<u>Description</u>
A	10.5" from inlet
B	9.5" from inlet
C	8.5" from inlet
D	7.5" from inlet
E	6.5" from inlet
F	5.5" from inlet
G	4.5" from inlet
H	3.5" from inlet
I	2.5" from inlet
J	1.5" from inlet
K	0.5" from inlet
L	inlet nozzle pressure
M	force-block signal
N	force-block excitation voltage
O	orifice exit pressure
P	orifice inlet pressure

$$\text{Pressure} = A + B(\text{volts}) + C(\text{volts})^2 + D(\text{volts})^3$$

pressure transducer	A	B	C	D
A	-6.049	3.926	-.17336	.01121
B	-7.059	4.234	-.22921	.01415
C	-.6491	3.934	-.16025	.00945
D	-7.056	4.692	-.34118	.01898
E	-7.009	4.152	-.20717	.01237
F	-6.389	3.933	-.16055	.00951
G	-6.589	3.956	-.16427	.00961
H	-6.588	3.908	-.15806	.00942
I	-6.595	3.949	-.16270	.00957
J	-6.353	3.927	-.16509	.00998
K	-6.203	3.846	-.14697	.00880
L	-20.207	11.157	-.08591	.00492
O	-20.668	11.068	-.07562	.01118
P	-18.827	11.928	-.17715	.01101

Figure 20. List of Polynomial Coefficients
for Pressure Transducer

values of pressure for each 140PC transducer and gives the mean and standard deviation for each from 0 to 45 psi in 5 psi increments. Appendix G depicts sample output of the program for a given pressure. Appendix H illustrates the program used to calibrate the 200PC pressure transducers. The program works as above, except values are taken from 0 to 60 psi at 5 psi increments.

Data obtained during calibration source pressure is plotted for each pressure transducer (Appendix I). Each plot was curve fitted with a third order polynomial. Figure 20 shows coefficients of the polynomial. These polynomials are used in the data acquisition/control program to convert transducer readings to pressure readings.

B. NOZZLE THRUST FORCE-BLOCK

The thrust produced by the nozzle was employed to deduce the nozzle exit velocities. The thrust was measured by instrumenting a target plate in the exit flow field. Appropriate screens were installed to prevent liquid "bounce back." The jet momentum force on the target is acquired by a balance beam system shown in Figure 21. A Kistler-Morse force block provides an analog signal proportional to the nozzle jet momentum.

The calibration of the force-block was completed by placing known weights on the force-block side of the balance

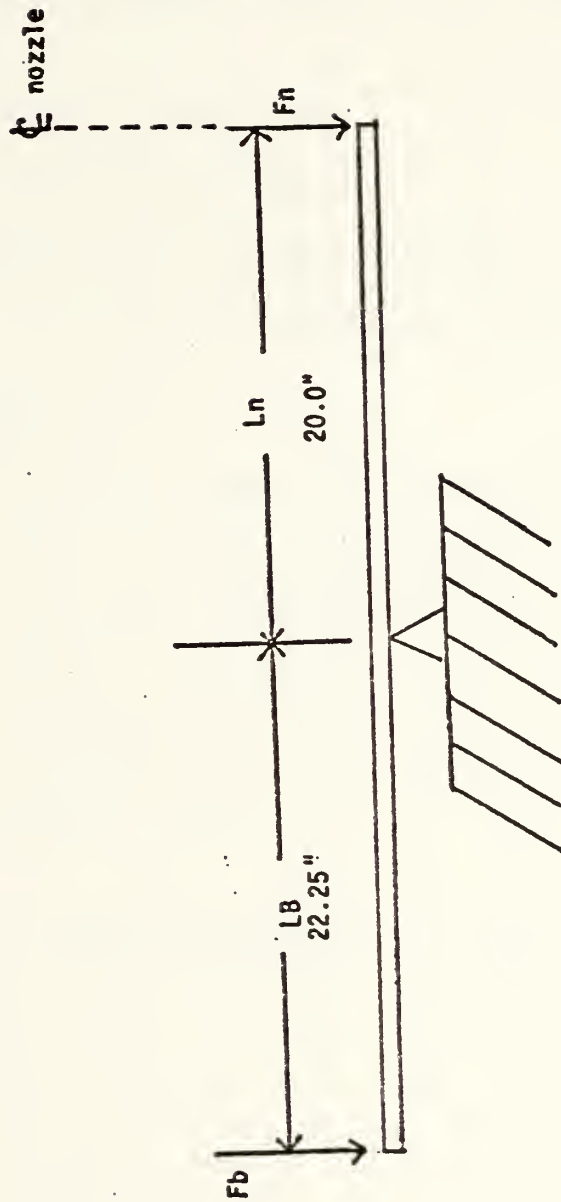


Figure 21. Force-Block Balance Beam Diagram

beam, (Figure 21), and recording the voltage produced. Appendix J shows results of this calibration. These results were curve fitted with a third order polynomial. The following is the volt-to-force conversion polynomial:

$$FB = (1/453.6)*(-234.396+48715.28*VOLTS-11261.54*VOLTS+33899.3*VOLTS)$$

$$FN = FB*LB/LN$$

$$FN = \text{FORCE AT NOZZLE EXIT (LBF)}$$

$$FB = \text{FORCE AT FORCE BLOCK (LBS)}$$

$$LB = \text{LENGTH FROM PIVOT TO FORCE BLOCK(IN.)}$$

$$LN = \text{LENGTH FROM PIVOT TO DIRECTIONAL OBSTRUCTION(IN.)}$$

C. FLOW MEASUREMENT

1. Air mass flow measurement for the system achieved by measuring the inlet and outlet pressure on a D-10512 orifice with a 0.92 inch bore. For details on orifice see Section III. Air flow is calculated in the data acquisition program. The program uses the following equation obtained from References 4 and 5.

$$M_{\text{air}} = K A_2 \sqrt{2G_c \rho_1 (P_1 - P_2)} \quad \text{where}$$

$$K = CE$$

$$E = 1/(1-B^4)^{1/2}$$

$$\beta = d/D$$

$$C = 0.60$$

$$A_2 = \text{AREA OF ORIFICE} = \frac{\pi D^2}{4} \quad \text{FT}^2$$

$G_c = 32.2 \text{ FT/SEC}^2$

$\rho_1 = \text{DENSITY LBM/FT}^3$

$P_1 = \text{PRESSURE AT INLET IN LBF/FT}^2$

$P_2 = \text{PRESSURE AT LUTLET IN LBF/FT}^2$

$M_{\text{air}} = \text{AIR MASS FLOW RATE LBM/SEC}$

The discharge coefficient C is the factor that accounts for losses through the orifice. Since the values of C varies from .62 to .60 for R_d number from 10^4 to 10^7 with $\beta = .3$, C will be considered constant.

2. Water flow measurement was made using two rotometers. Calibration of the rotometers were made by measuring the time for a given weight of fluid flow. The mass flow rate was calculated and plotted versus the rotometer reading. Appendix K is the plot of the results. The plot was curve fitted with a third order polynomial. The following is that polynomial:

$$MH20 = -.0063268 + .002097278 * RR - .00000658 * RR^2 + 1.1 \times 10^{-6} * RR^3$$

where $RR = \text{rotometer reading}$

D. DATA ACQUISITION/CONTROL SYSTEM

The heart of the data acquisition system is a HP9826 small computer. The HP9826 communicates via a Hewlett Packard 3497A data acquisition/control system. This system gathers data from the pressure transducers and nozzle thrust force-block. It converts the analog signal to digital data, and stores the data in memory. Figure 22 shows a pressure transducer to A/D converter channel connection, and Figure 23

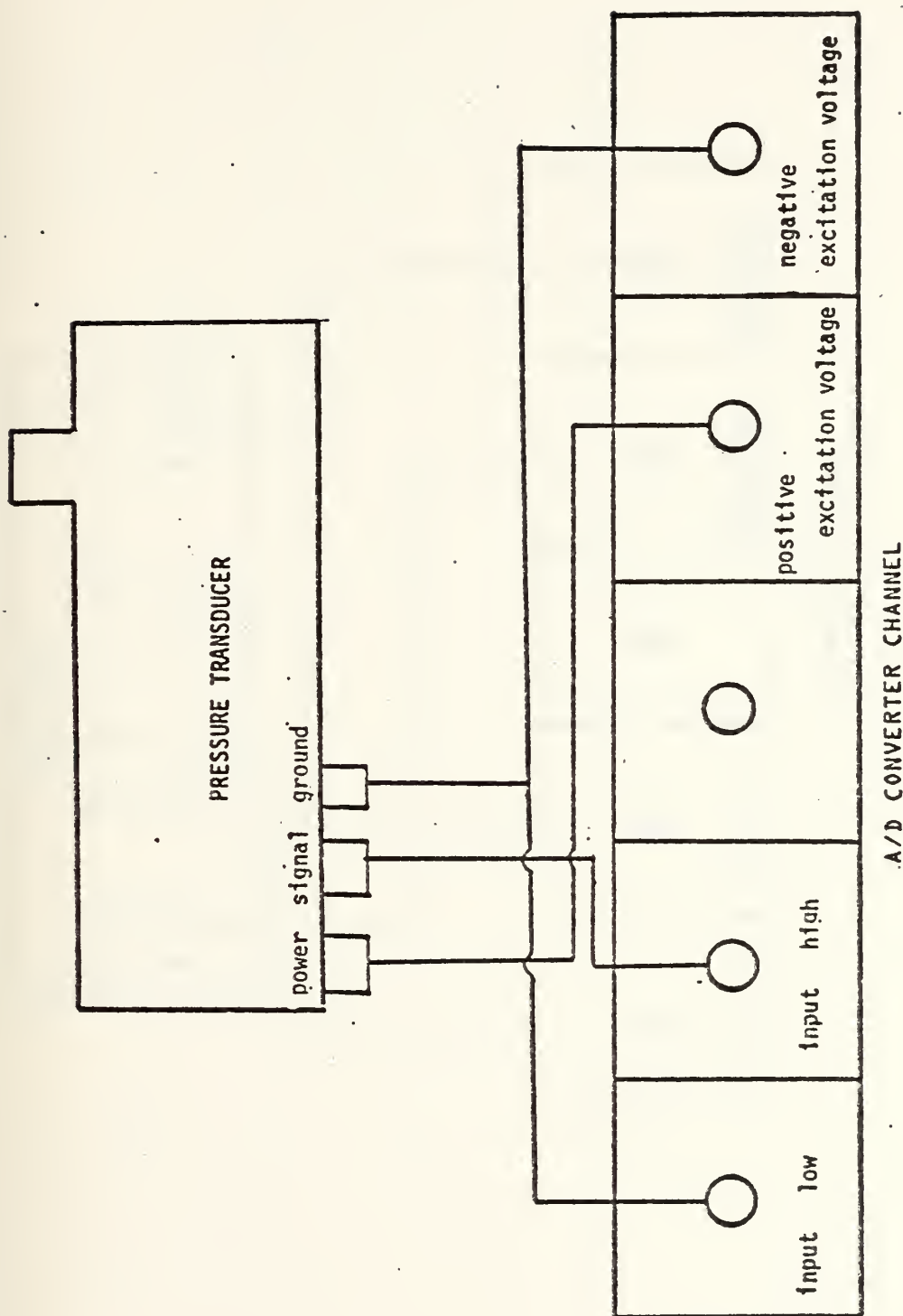


Figure 22. Transducer-to-Channel Connection

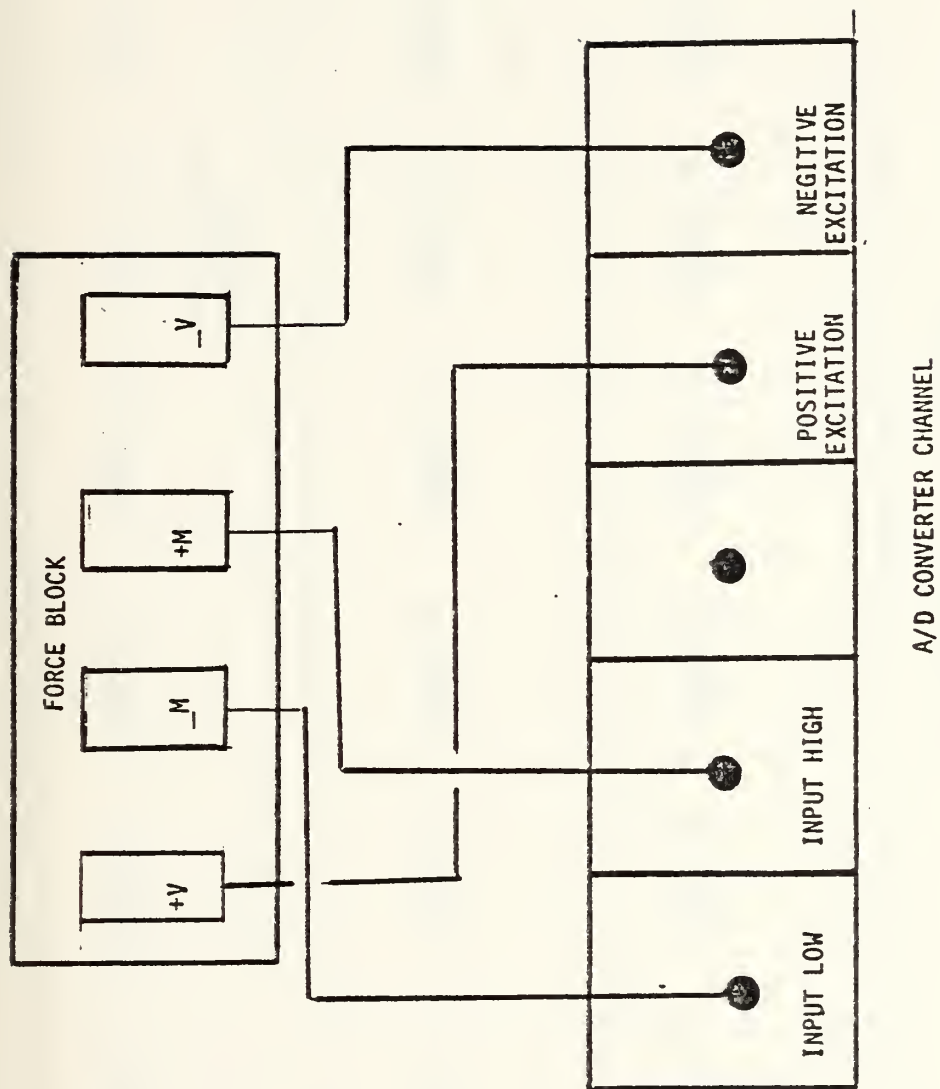


Figure 23. Force-Block-to-Channel Connection

CHANNEL 7	CHANNEL 8	CHANNEL 9	CHANNEL 16	CHANNEL 17	CHANNEL 18
G	H	I		EXCITATION VOLTAGE	

CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 13	CHANNEL 14	CHANNEL 15
D	E	F	O	P	M,N

CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 10	CHANNEL 11	CHANNEL 12
A	B	C	J	K	L

BUS CONNECTION TO A/D CONVERTER

Figure 24. Bus Connection-to-A/D Converter Connections

the force-block to A/D converter channel connection. Figure 24 depicts the current connection to the data acquisition/control system bus from the sensors.

The data acquisition and analysis program is a fully automated system which integrates the use of the HP9826, HP3497A, and all sensor devices. The program can be divided into three sections:

1. Data Acquisition - Data is acquired from 15 different sensor devices. All system parameters are initialized and configuration types are inputted into the computer memory for future use. Ten readings are made on each sensor and a mean value for each is calculated and stored in memory.
2. Data Conversion - Input data conversion is completed by using calibration information obtained on each pressure transducer and force-block. The program takes the stored mean values from memory, and converts the input voltage to a pressure or force using the third order calibration polynomial for each sensor.
3. Data Analysis - This is the heart of the program in that all performance parameters are calculated and printed. It uses all of the above information to calculate mass flow rate of water, mass flow rate of air, total mass flow rate, thrust, mixture

ratio, exit velocity and all pressure informa-

tion. The following equations are also used:

$$\text{Exit Velocity} = (\text{Thrust} / \text{Total Mass Flow Rate}) * g_c (\text{ft/sec})$$

$$\text{Mixture Ratio} = \dot{m}_{\text{water}} / \dot{m}_{\text{air}}$$

$$\text{Total Mass Flow Rate} = \dot{m}_{\text{water}} + \dot{m}_{\text{air}} \left(\frac{\text{lbm}}{\text{sec}} \right)$$

Appendix L is the data acquisition program and sample output.

VI. EXPERIMENTAL RESULTS

Six test runs were made using the equipment described in the previous sections. It was found that the inlet pressure to the nozzle remained nearly constant for each setting. The testing was conducted by maintaining a constant air control valve setting and varying the mass flow rate of water. The regulator outlet pressure of the nitrogen bottle which controls the air valve was set at 30 psi and 15 psi. These settings correspond to nozzle inlet pressure of 35 ± 1.0 psi and 29 ± 1.0 psi respectively. For each nozzle inlet pressure, experimental data was obtained at varying mass ratios of water-to-air in the range of 2 to 13. These experiments were conducted with three discharge area ratios ($A_{\text{inlet}}/A_{\text{out}}$). Those ratios are: 3.586, 2.600, and 1.9259. The results of the six experimental tests are displayed in Tables II through VII.

Inlet air was limited to a maximum value of 40 psi. The 140PC pressure transducer's maximum output pressure is 40 psi, (see information on 140PC transducer Figure 21). The experimental system has the ability to reach higher pressures. The present configuration may be operated to 70 psig.

Table II. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN*****PRESSURE 29.00000 PSI									

*****MASS FLOW RATE*****		*****WATER*****		*****MASS RATIO*****		*****EXPERIMENTAL EXIT VELOCITY*****		*****REAL EXIT VELOCITY*****	
TOTAL		AIR						THRUST	
*****		*****		*****		*****		*****	
0.06050	0.01830	0.04220	2.30000	1994.00000	1950.39900	3.75000			
0.10150	0.01840	0.08346	4.62000	1243.30000	1300.00000	3.92000			
0.13650	0.01790	0.11860	6.64000	969.69990	1001.89900	4.11000			
0.16630	0.01770	0.14860	8.39000	806.10000	830.60000	4.16000			
0.19220	0.01770	0.17450	9.83000	710.69990	760.30000	4.24000			
0.21490	0.01750	0.19730	11.26000	643.19990	695.50000	4.29000			
0.23580	0.01750	0.21810	12.39000	602.50000	642.00000	4.41000			
0.25550	0.01760	0.23790	13.51000	550.00000	620.89990	4.37000			

Table III. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY		0.45313 SQ-IN	PRESSURE		35.00000 PSI	*****			
*****MASS FLOW RATE*****		MASS		EXPERIMENTAL		REAL		*****	
TOTAL	AIR	WATER	RATIO	EXIT	VELOCITY	EXIT	VELOCITY	THRUST	*****
0.06300	0.02080	0.04220	2.02000	2440.50000	2430.30000			4.77000	*****
0.10410	0.02060	0.00346	4.05000	1536.10000	1611.50000			4.97000	*****
0.13890	0.02030	0.11860	5.85000	1192.19900	1240.69900			5.14000	*****
0.16840	0.01980	0.14860	7.50000	1007.30000	1031.30000			5.27000	*****
0.19450	0.02000	0.17450	8.73000	880.83000	930.80000			5.32000	*****
0.21720	0.01990	0.19730	9.93000	810.60000	860.75000			5.47000	*****
0.23020	0.02000	0.21810	10.89000	735.69990	810.50000			5.44000	*****
0.25750	0.01950	0.23790	12.18900	669.19990	715.30000			5.34000	*****

Table IV. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY		0.62500	SQ. IN.	*****PRESSURE		29.00000	PSI	***** EXPERIMENTAL REAL *****			
		MASS FLOW RATE*****		MASS RATIO		EXIT VELOCITY		EXIT VELOCITY		THRUST	
		TOTAL		WATER		*****		*****		*****	
		*****		*****		*****		*****		*****	
		0.06040		0.01820		0.04220		1834.50000		1880.30000	
	0.10150	0.01810	0.08346	4.61000	1158.00000	1201.19900	3.66000				
	0.13660	0.01800	0.11860	6.59000	937.80000	953.60000	3.98000				
	0.16650	0.01790	0.14860	8.32000	802.19990	803.10000	4.15000				
	0.19220	0.01770	0.17450	9.85000	688.60000	749.19990	4.21000				
	0.21510	0.01780	0.19730	11.10000	643.19990	702.10000	4.30000				
	0.23550	0.01740	0.21810	12.60000	589.89990	670.10000	4.32000				

Table V. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 35±1.5psi

[illegible]

Table VI. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY	0.84375 SQ.IN*****	PRESSURE	29.00000 PSI
TOTAL MASS FLOW RATE	AIR	WATER	EXPERIMENTAL REAL EXIT VELOCITY THRUST
0.06110	0.01890	0.04220	2.23000 1586.69900 1653.39900 3.01000
0.10210	0.01860	0.08346	4.48000 1069.10000 1101.60000 3.39000
0.13700	0.01840	0.11860	6.44000 850.39990 900.89990 3.61000
0.16680	0.01820	0.14860	8.19000 754.69990 791.10000 3.91000
0.19250	0.01800	0.17450	9.69000 655.60000 720.10000 3.92000
0.21560	0.01820	0.19730	10.84000 596.80000 675.30000 3.99000
0.23610	0.01800	0.21810	12.14000 576.10000 638.19990 4.22000
0.25560	0.01770	0.23790	13.46000 570.50000 610.50000 4.52000

VII. DISCUSSION

The results of this investigation are in two parts; the experimental test results and the computer outputs based on initial conditions similar to those of the experiments.

The key variables are: the nozzle overall area ratio A_R , liquid/air mass flow ratio, nozzle exit velocity, nozzle supply pressure, nozzle thrust, and the nozzle axial pressure profiles. Figures 25 through 34 present the exit velocity vs. mass ratio results for the experiment and computer output. Figure 29-34 illustrates the comparison of the experimental results and the corresponding computer output. Figure 35 illustrates the variation of nozzle thrust with mass ratio for different area ratios and inlet pressures. Figures 36 and 37 present the axial pressure profiles.

In all cases the exit plane velocity decreases as the liquid/air mass ratio is increased. In the low mass ratio range (i.e., less than ≈ 5) the velocity decrease is very pronounced. Past a mass ratio value of ≈ 10 the velocity of the mixture becomes relatively insensitive to the mixture ratio. This is as would be expected. For the same inlet conditions there is a fixed amount of energy available for conversion to its kinetic form. In the nozzle process the energy is conserved and thus an increasing mass ratio is

manifested in a decreasing exit plane velocity. In all cases the agreement between the experimental tests and the analytic predictions are within $\sim 10\%$.

There also was apparent and a consistent trend with respect to the nozzle area ratio and the exit velocity. As the nozzle exit area was increased the exit velocity of the mixture decreased. The effect seems to be more pronounced at the lower mass ratios. This trend was confirmed by observations of the actual flow field in the nozzle. If the exit area was increased significantly (beyond the max area used in those tests) there was evident an abrupt and severe separation within the diverging portion of the nozzle passage. This was accompanied by a drastic decrease in exit velocity as evidenced by the output from the thrust target. It appears that the diverging portion of the nozzle, at a certain point, starts to behave as a subsonic diffuser and hence experiences an adverse pressure gradient. This reasoning is in part confirmed by the pressure profiles identified in Figures 36 and 37.

The relationship between measured thrust and mass ratio (Figure 35) indicates a slightly increasing trend. This may be explained by considering the following. Each set of data points (at constant inlet air pressure and constant nozzle exit area) is developed by varying the mass ratio. This, in turn, is achieved by increasing the liquid rate by increasing the liquid supply pressure. The net result is an

increase in the liquid inlet velocity or an increase in the inlet energy level. Thus a particular data set is not truly at a constant inlet energy level but is increasing.

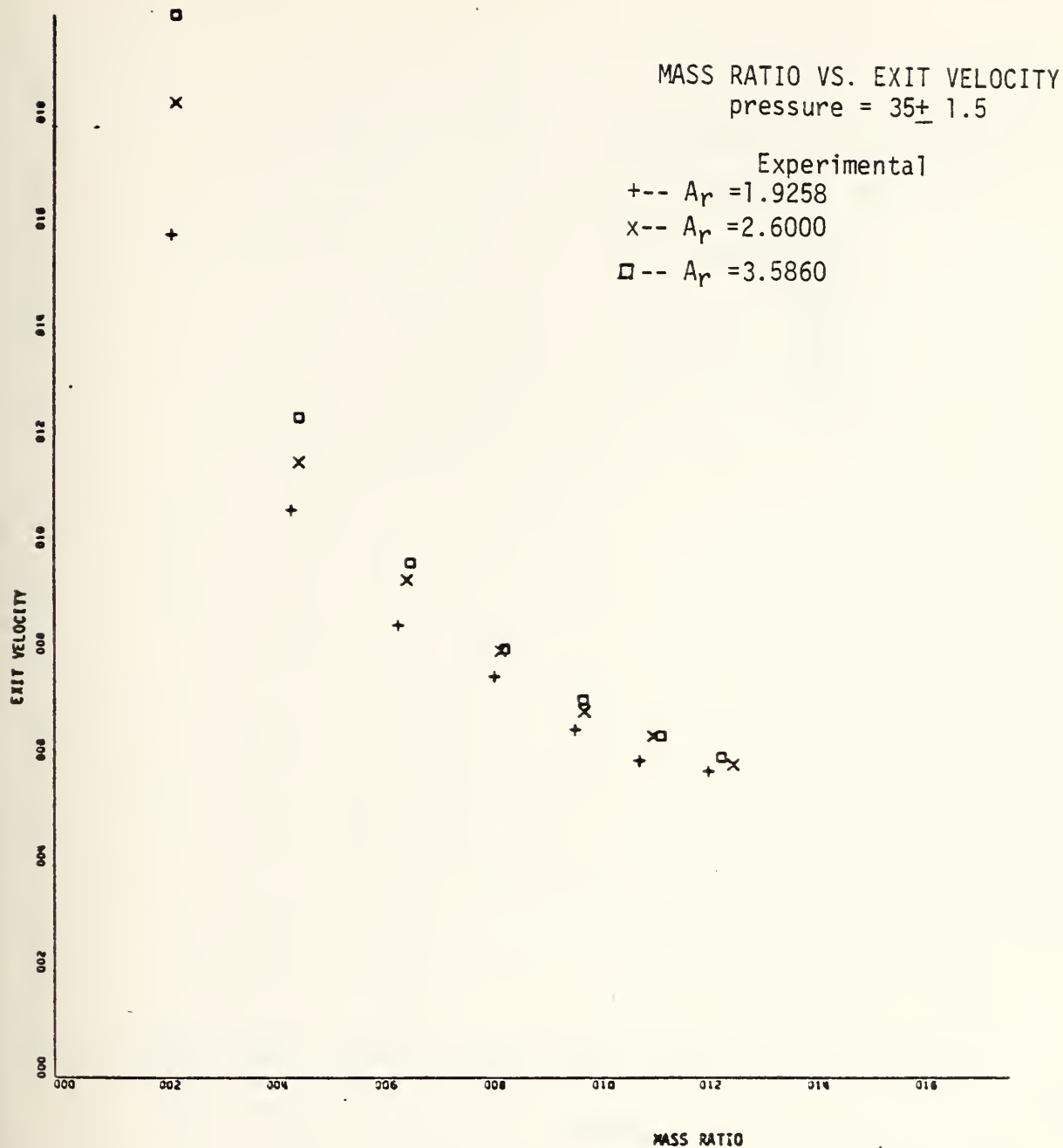
Perhaps the major discrepancy between the experimental test results and the computer analytic model is evidenced in the axial pressure profiles of Figures 36 and 37. It is clearly evident that at a certain point the nozzle passage reverts from a nozzle to a diffuser. This transition point occurs slightly downstream of the throat and the pressure starts to increase.

Unfortunately the computer analytic model requires a pressure profile as an input. Furthermore the pressure profile must be continuously decreasing. Thus the profile as obtained from the experiment are not directly useable. The situation is examined with the aid of Figure 38. Curve A is a typical axial pressure distribution as obtained from the experiment. Curve B is a pressure distribution used by Elliott in the application of his computer program. Pressure profiles C and D were arbitrarily defined and the exit plane velocity for each was calculated. Velocity variation in the range of 1% is evident. It appears that the final exit velocity is relatively insensitive to the actual pressure profile in the nozzle.

In light of the preceeding difficulty of matching the experimental pressure profile to the computer model and the

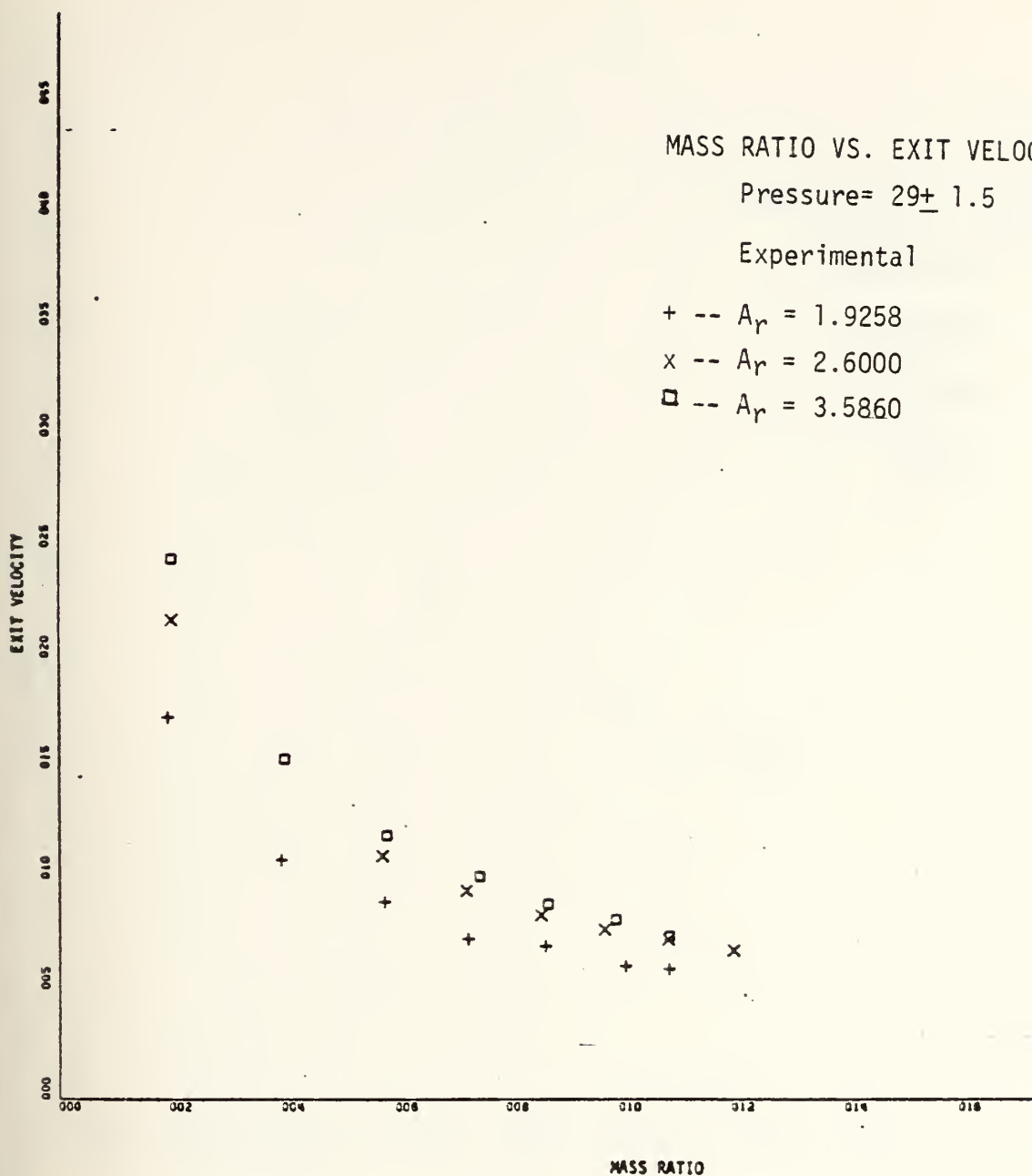
apparent flexibility of the type of pressure profile it was decided to employ a form of profile D of Figure 38. Thus instead of using the actual experimental pressure data as an input in the computer model, a profile resembling curve D was developed for each inlet pressure case.

It is apparent that within certain rather wide limits the Elliott computer model yields results that correspond within 10% to results obtained from the experiment. The general trends have been confirmed and their behavior has revealed nothing unexpected. The conclusion of Elliott [Ref. 1] has been largely substantiated. "It is very difficult to design a bad or a good dual-phase nozzle."



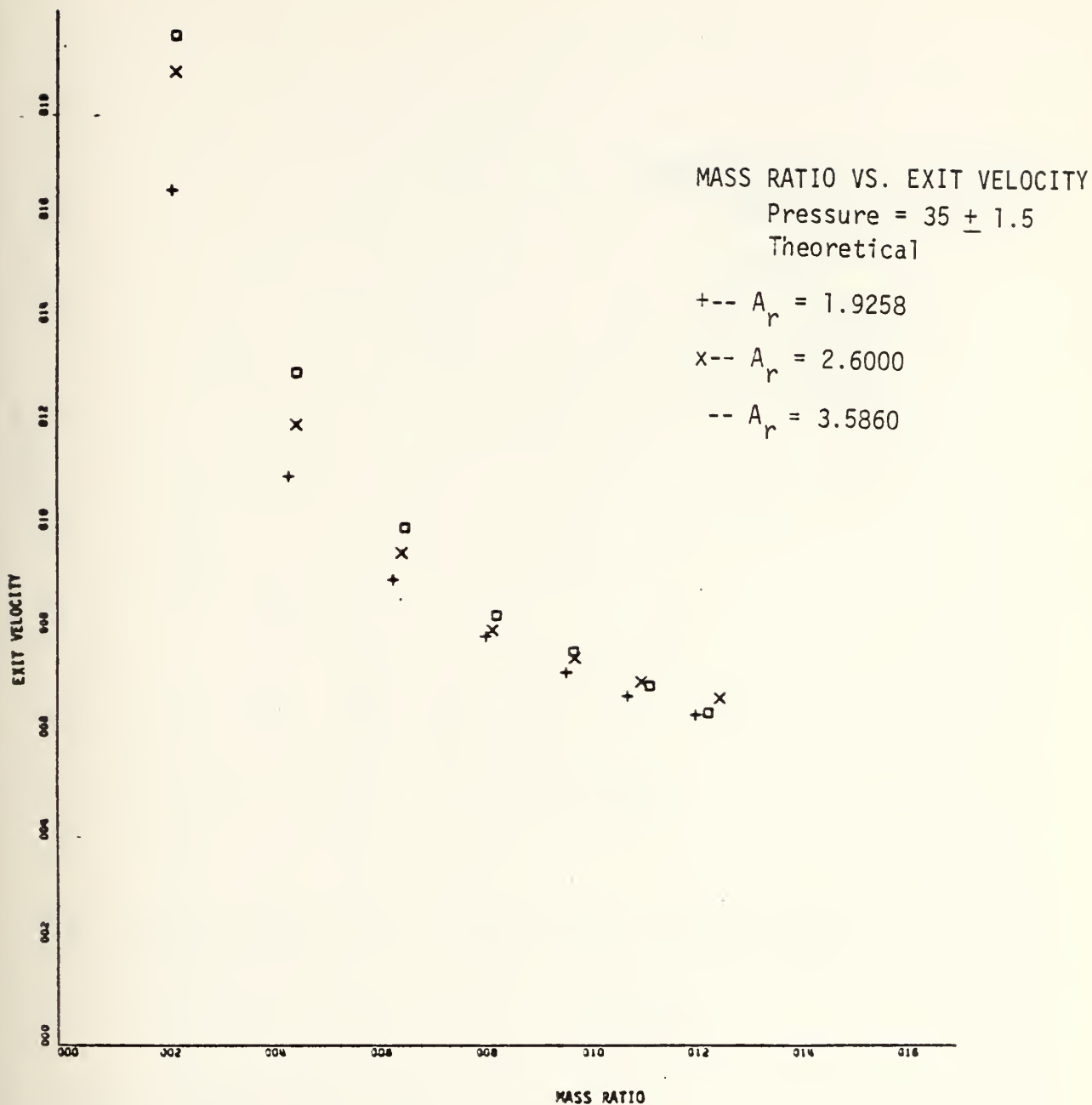
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 25. Mass Ratio vs. Exit Velocity at
Pressure = 35 ± 1.5 psi Experimental



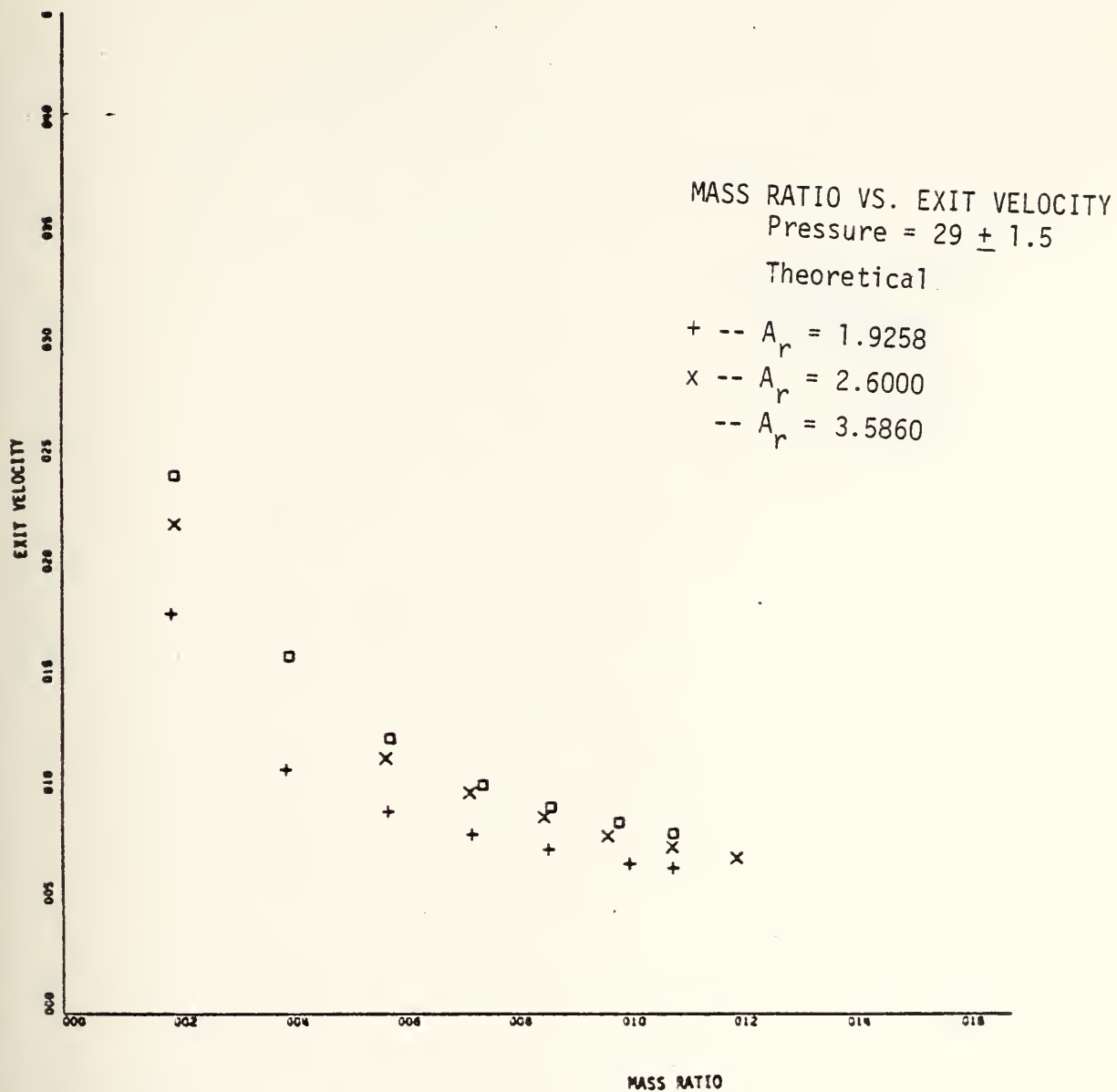
X-SCALE=2.00E+00 UNITS INCH.
 Y-SCALE=5.00E+02 UNITS INCH.

Figure 26. Mass Ratio vs. Exit Velocity at
 Pressure = 29 ± 1.5 psi Experimental



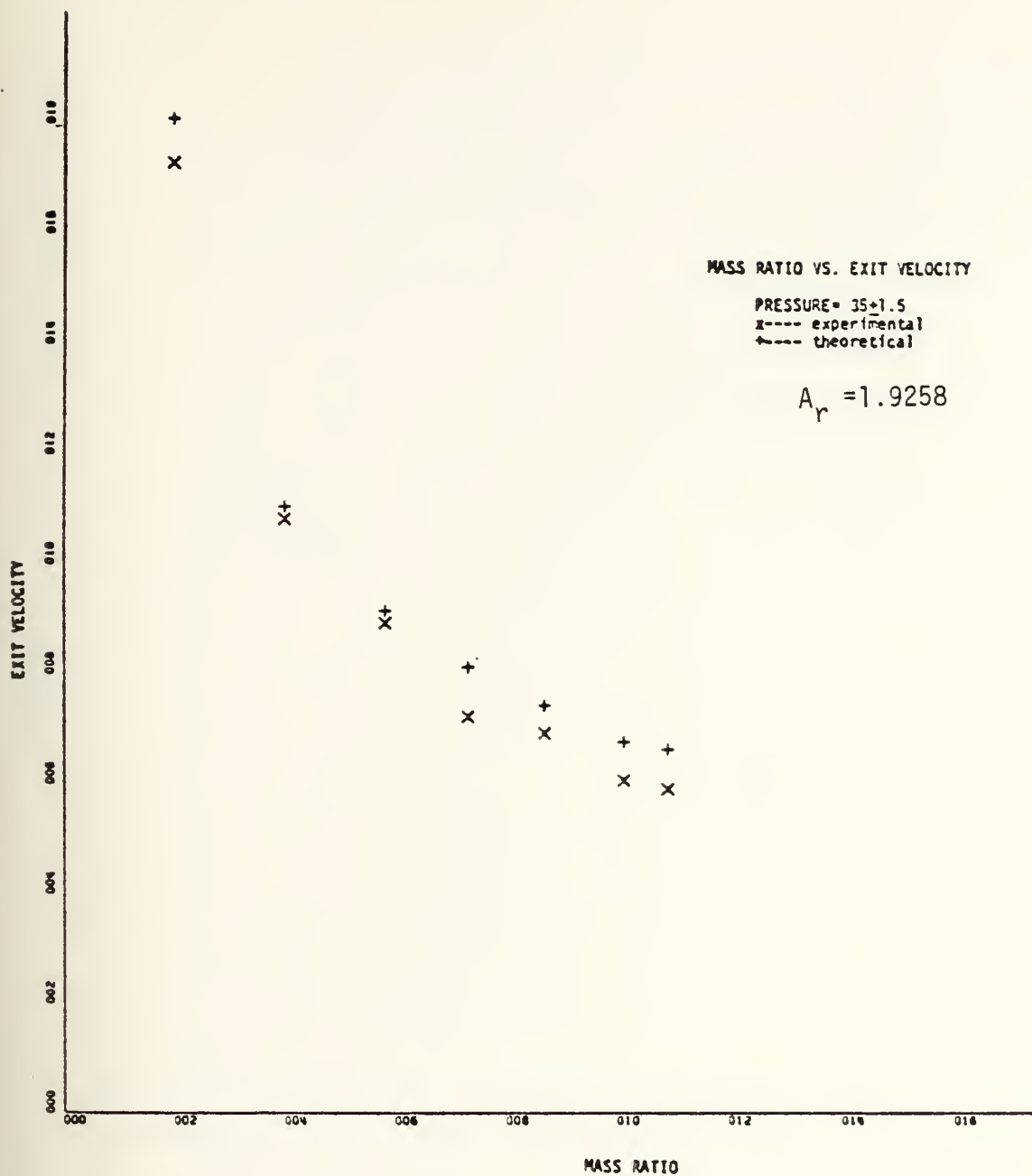
X-SCALE=2.00E+00 UNITS INCH.
 Y-SCALE=2.00E+02 UNITS INCH.

Figure 27. Mass Ratio vs. Exit Velocity at
 Pressure = 35 ± 1.5 psi Theoretical



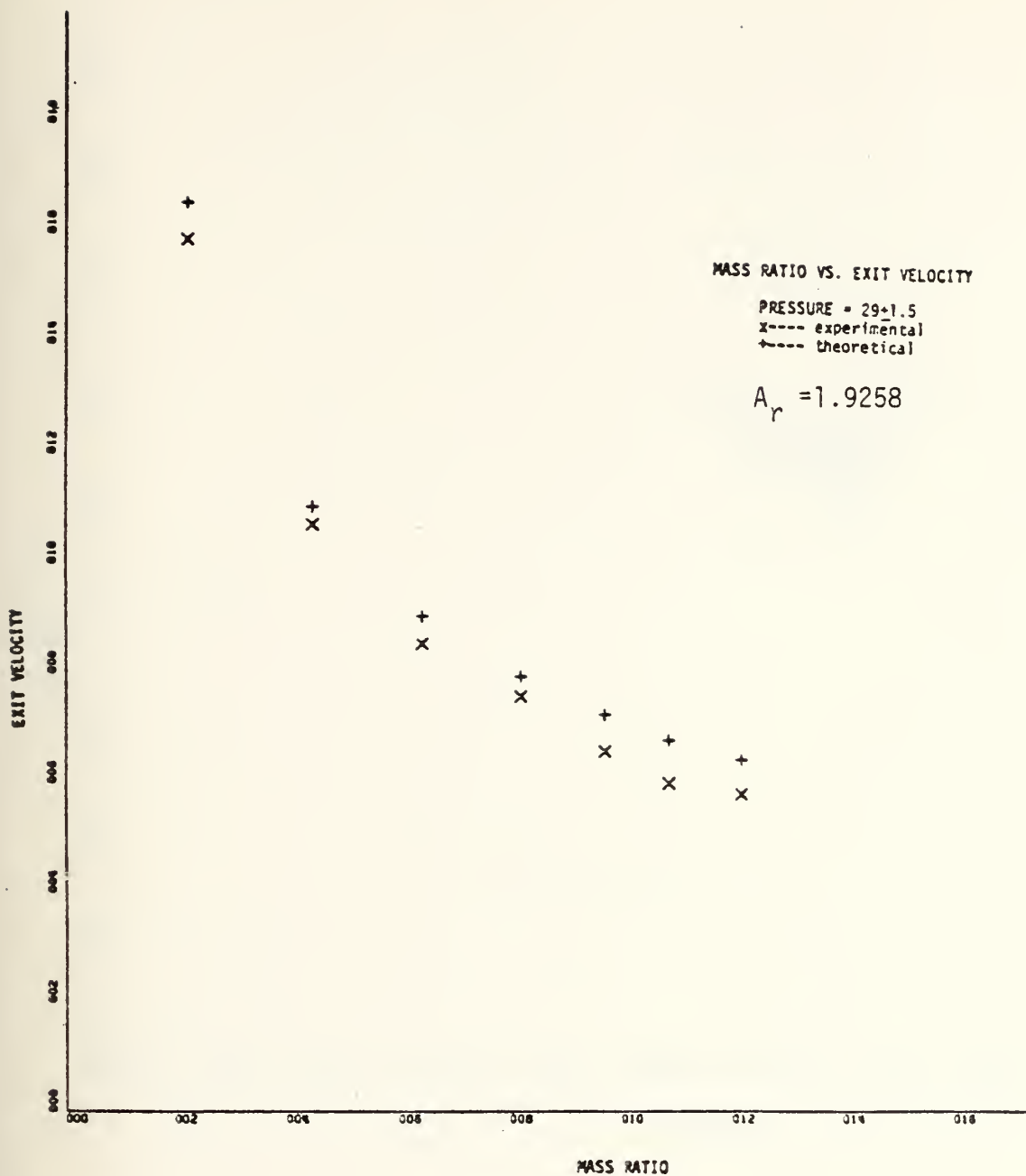
X-SCALE=2.00E+00 UNITS INCH.
 Y-SCALE=5.00E+02 UNITS INCH.

Figure 28. Mass Ratio vs. Exit Velocity at
 Pressure = 29 ± 1.5 psi Theoretical



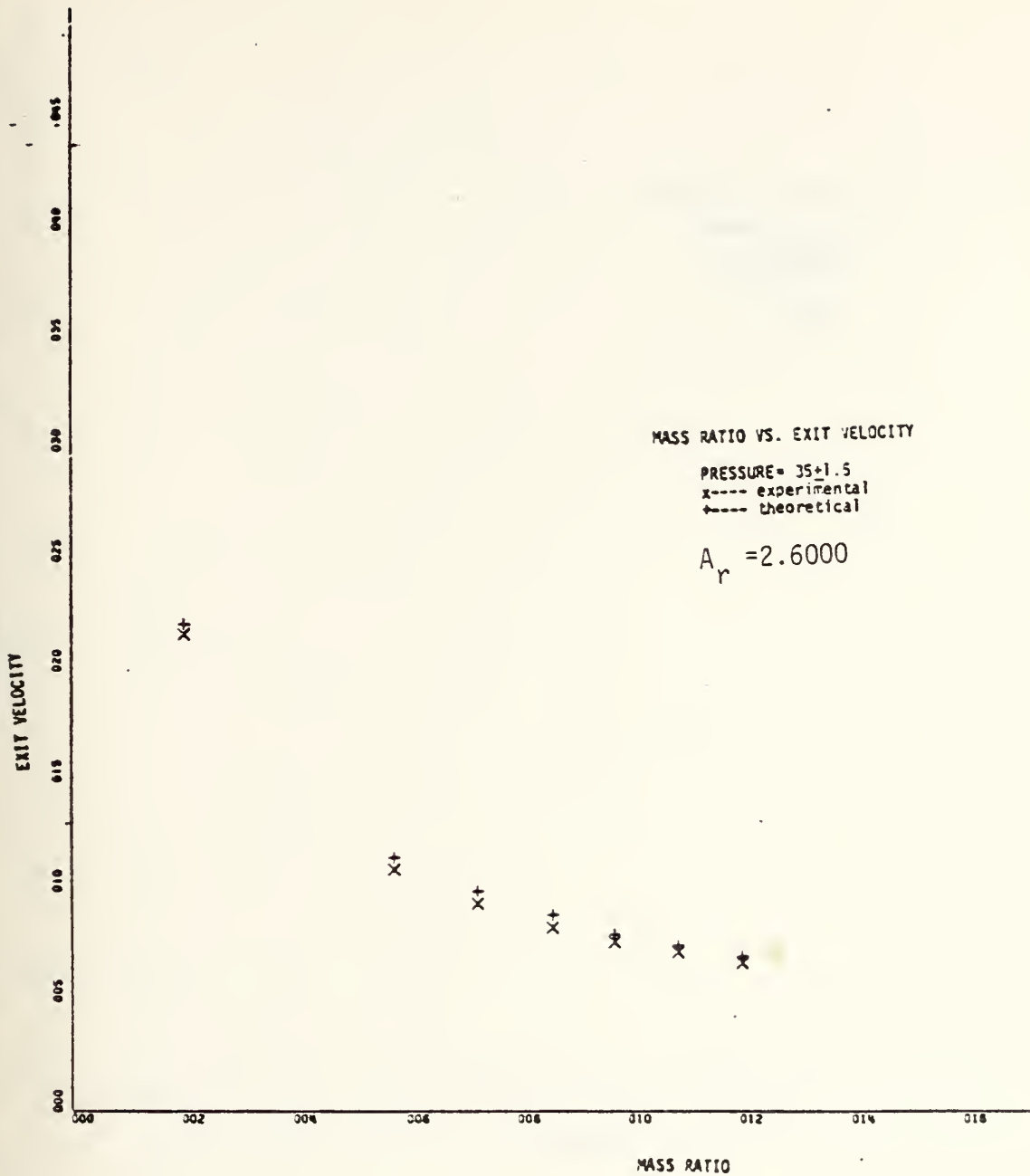
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 29. Mass Ratio vs. Exit Velocity at
Pressure = 35±1.5psi Area = .84375



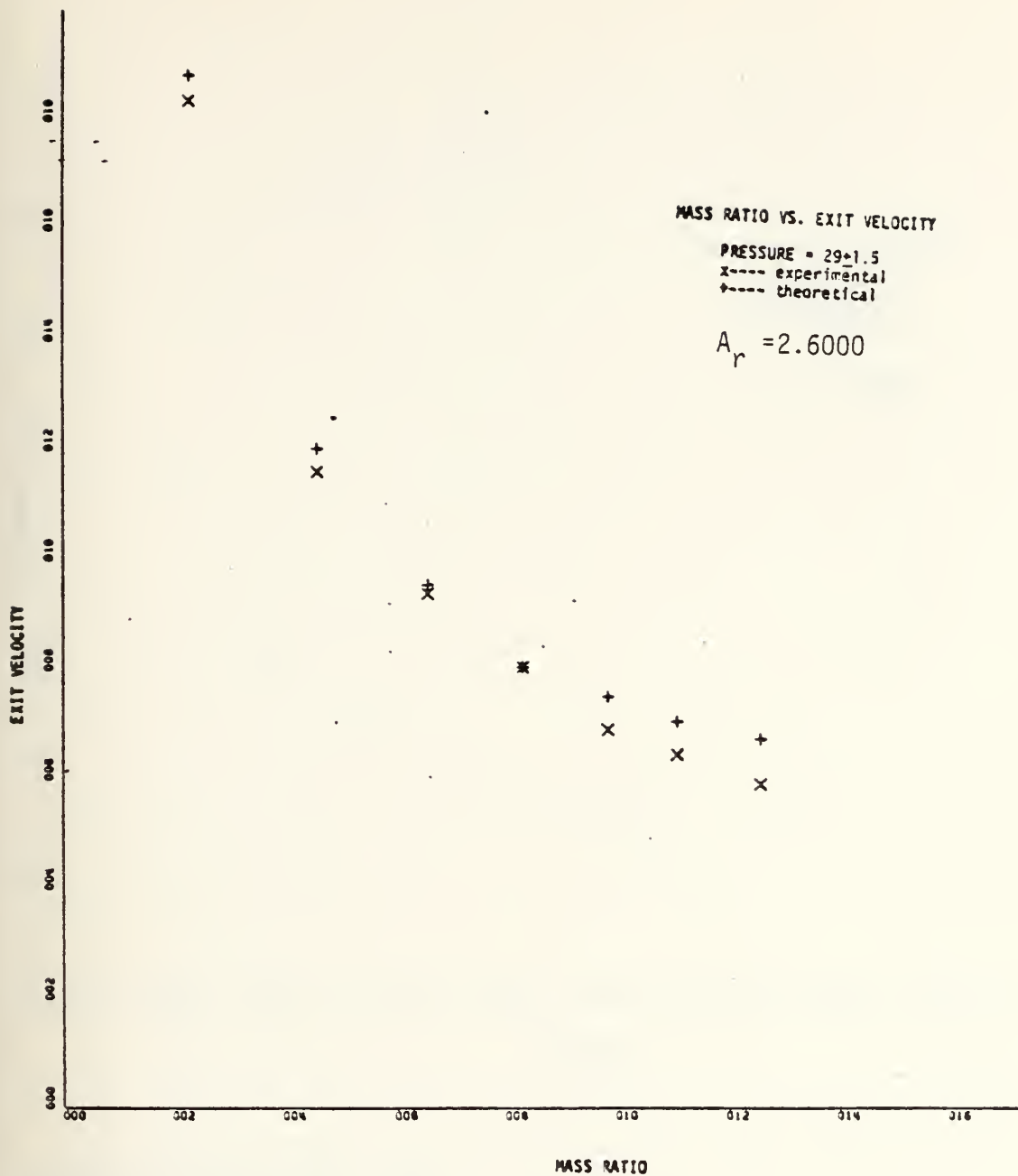
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 30. Mass Ratio vs. Exit Velocity at
Pressure = 29±1.5psi Area = .84375



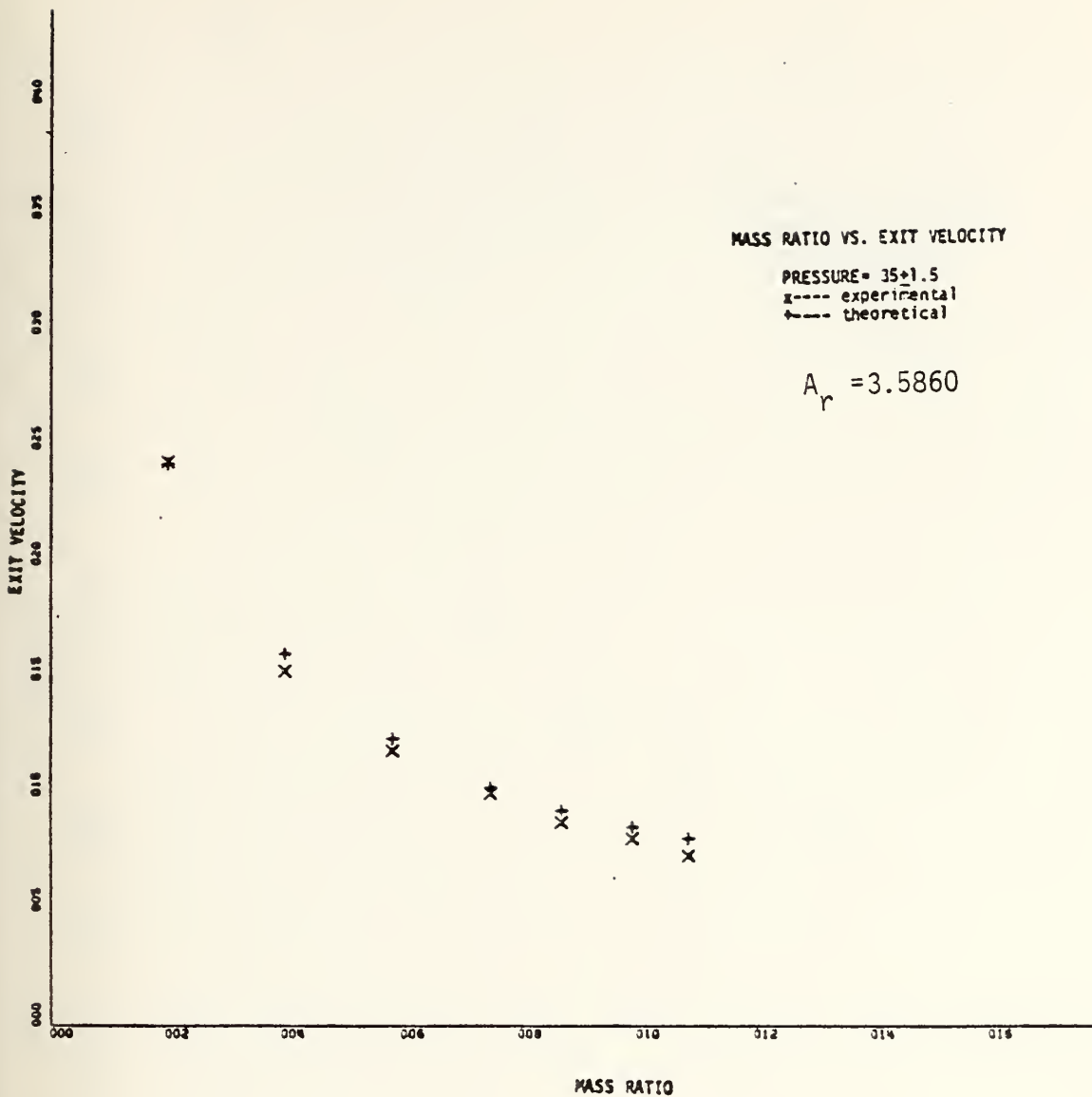
X-SCALE = $2.00E+00$ UNITS INCH.
Y-SCALE = $5.00E+02$ UNITS INCH.

Figure 31. Mass Ratio vs. Exit Velocity at
Pressure = 35 ± 1.5 psi Area = .62500



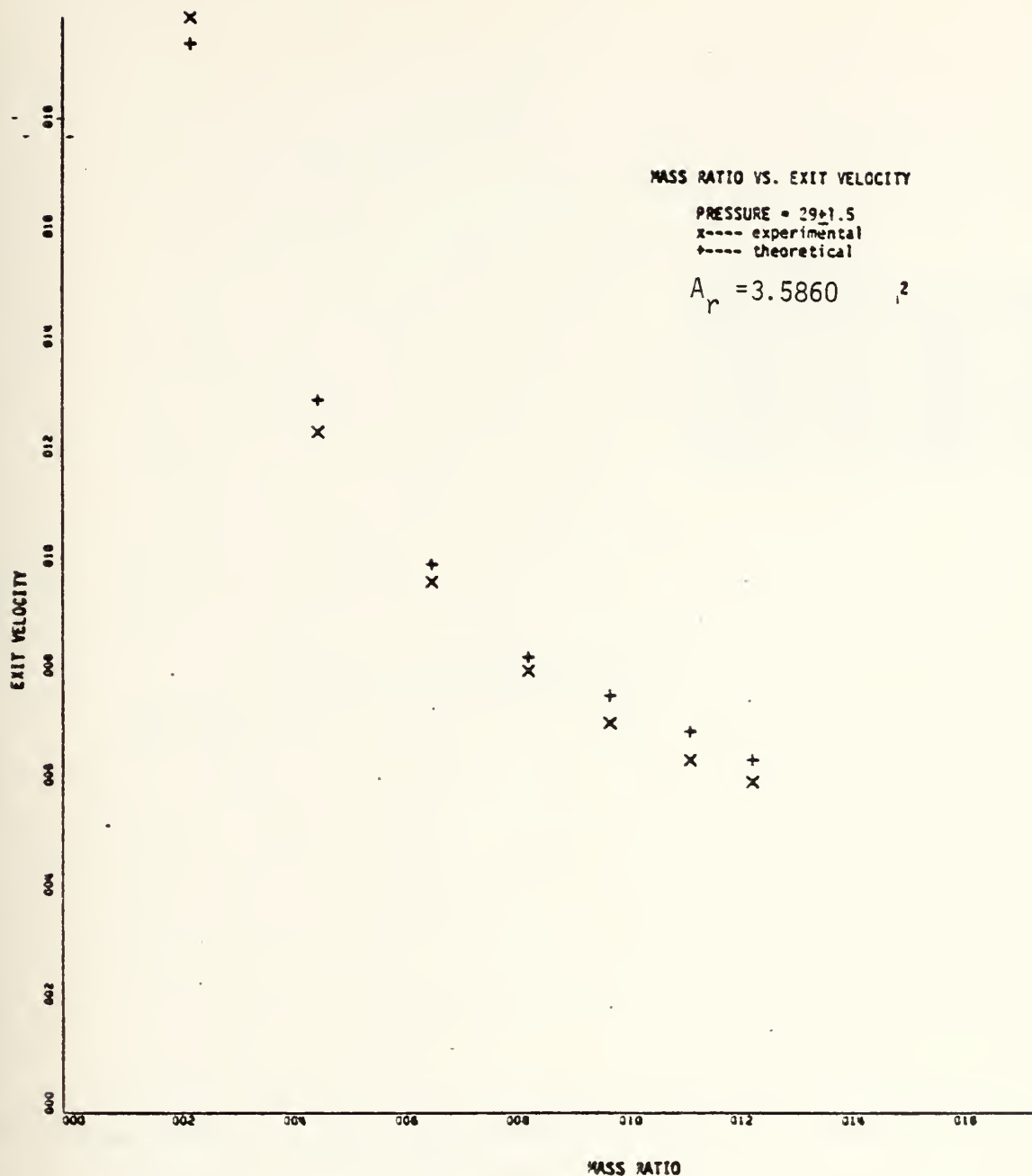
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 32. Mass Ratio vs. Exit Velocity at
Pressure = 29±1.5psi Area = .62500



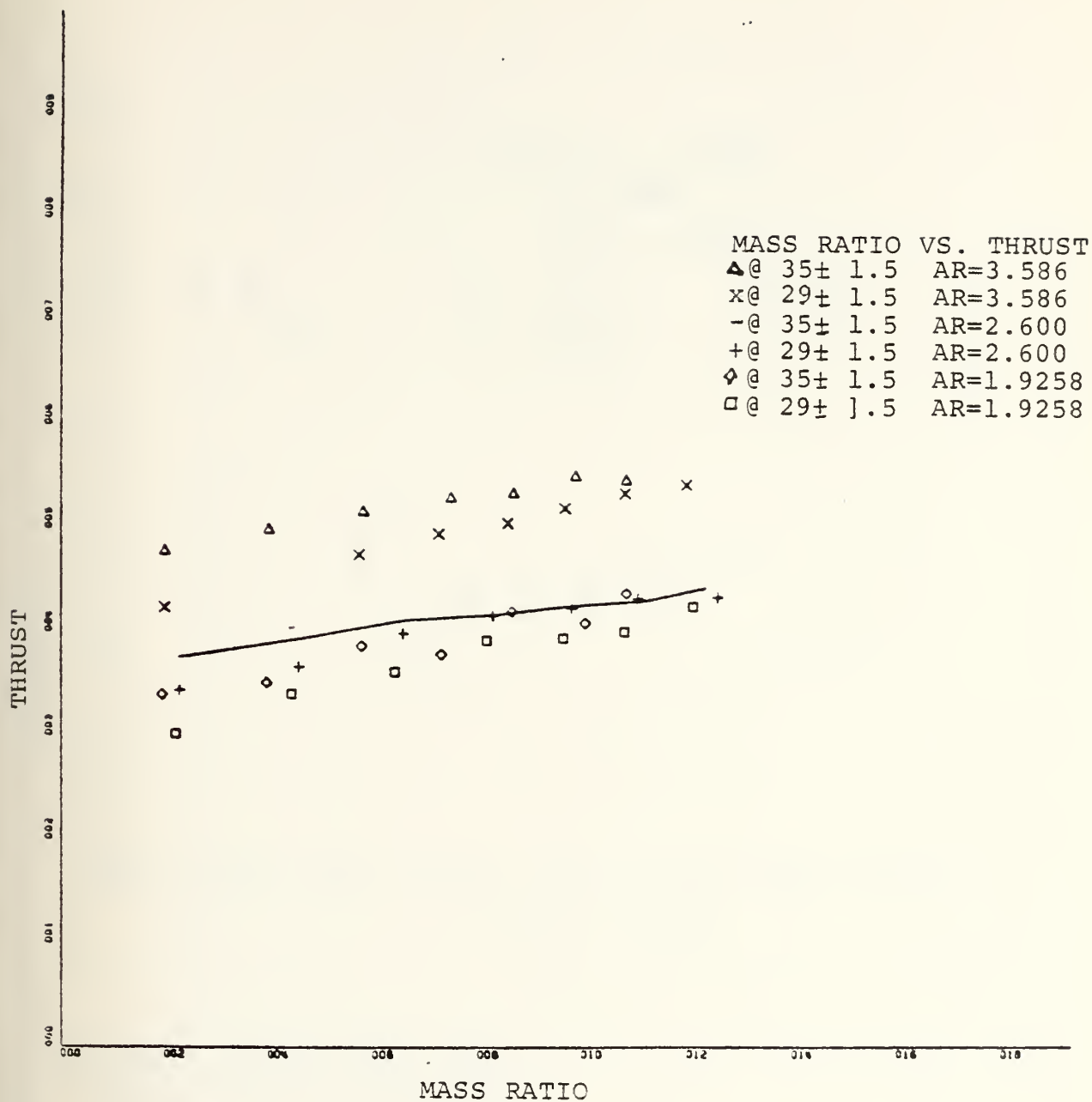
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 33. Mass Ratio vs. Exit Velocity at
Pressure = 35±1.5psi Area = .45313



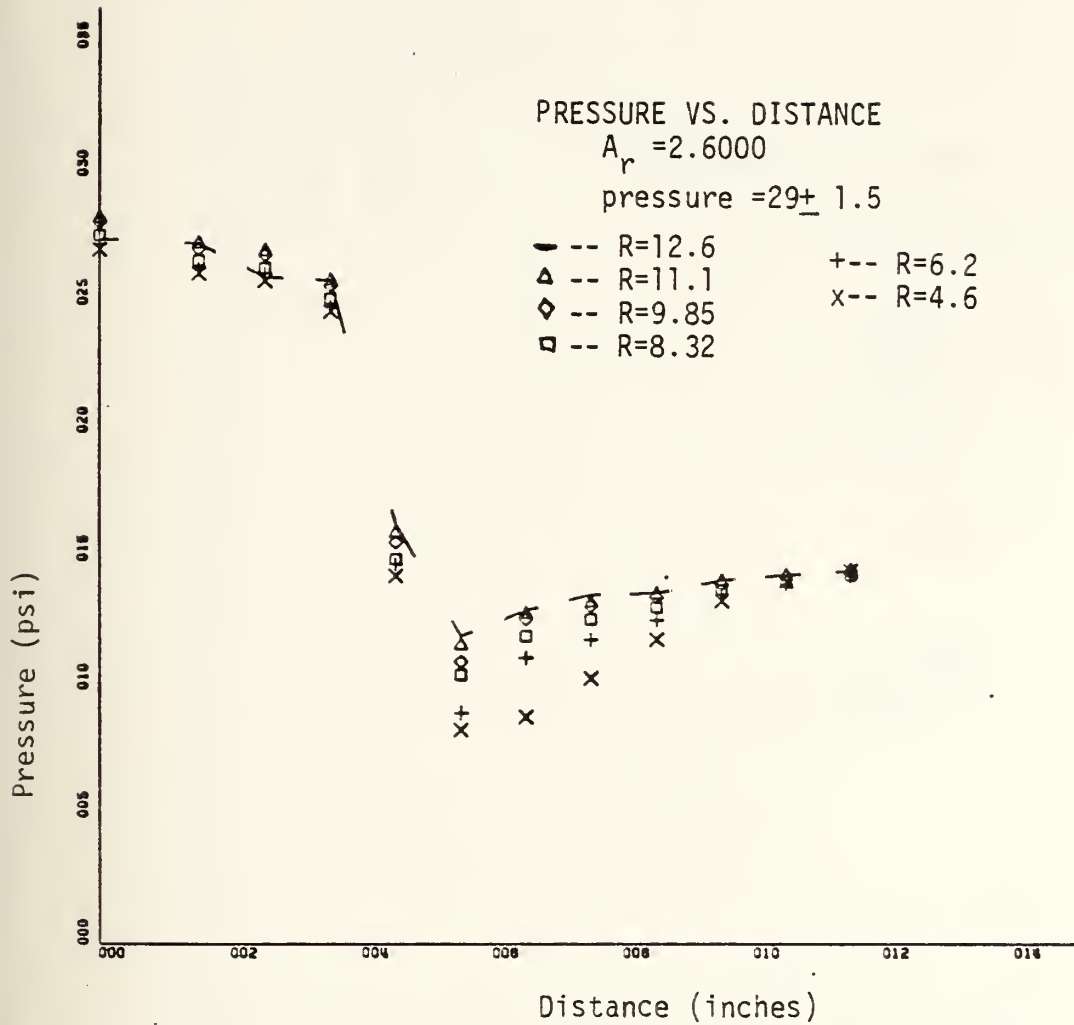
X-SCALE=2.00E+00 UNITS INCH.
 Y-SCALE=2.00E+02 UNITS INCH.

Figure 34. Mass Ratio vs. Exit Velocity at
 Pressure = 29 ± 1.5 psi Area = .45313



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=1.00E+00 UNITS INCH.

Figure 35. Mass Ratio vs. Thrust Curve



X-SCALE=2.00E+00 UNITS INCH.
 Y-SCALE=5.00E+00 UNITS INCH.

Figure 36. Pressure vs. Distance at Pressure
 = 29 ± 1.5 Exit Area = .625 sq. in.

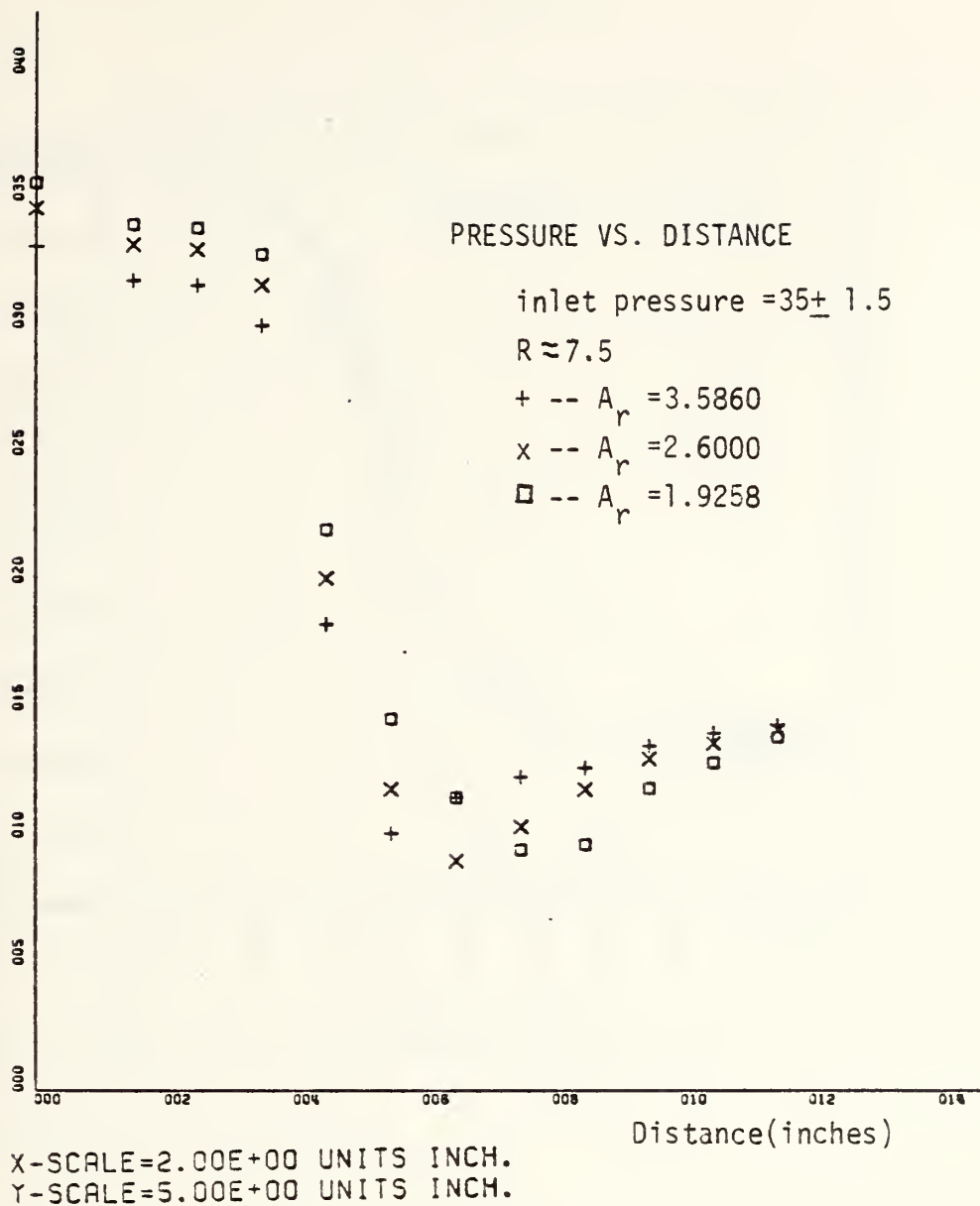


Figure 37. Pressure vs. Distance at
 $R \approx 7.5$ $P = 35 \text{psi} \pm 1.5$

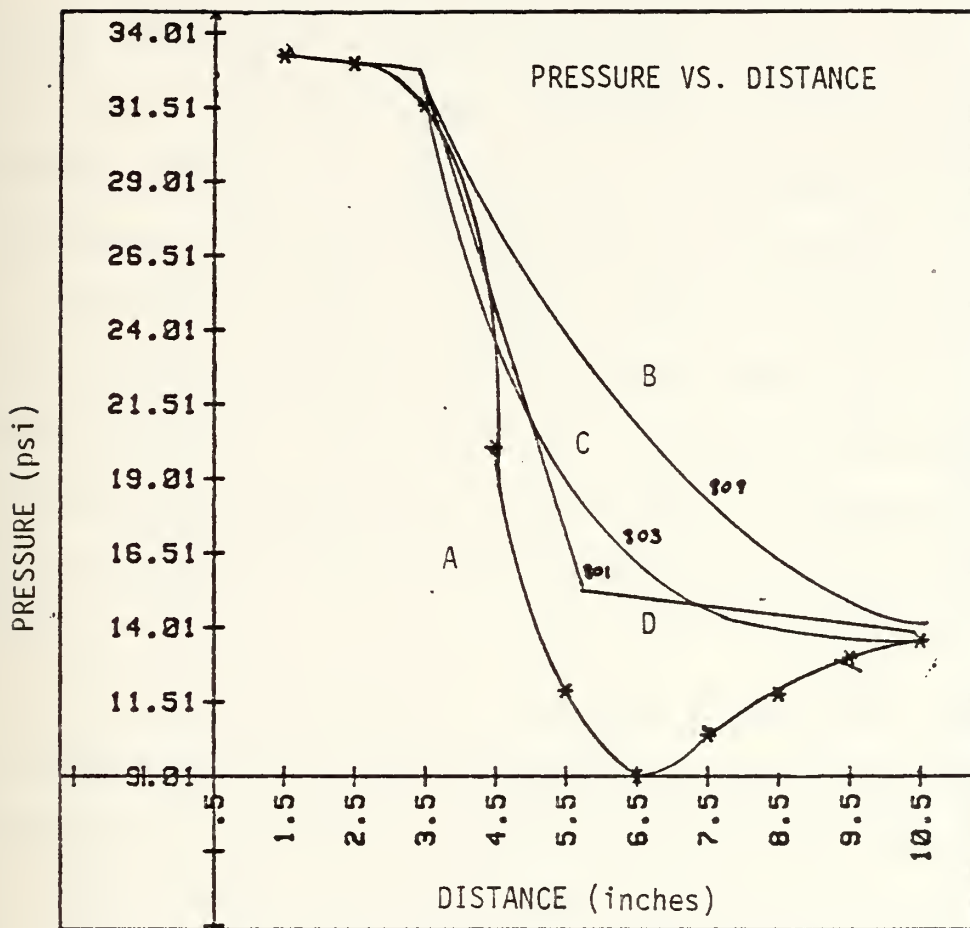


Figure 38. Various Pressure Profiles & Corresponding Exit Velocities

VIII. CONCLUSION

A set of experiments were conducted with an air-water mixture flowing at a mass ratio from 2 to 13. The experiments correlated well with a dual-phase two-component computer program. It appears that the program will permit prediction of the exit velocities to an accuracy of 10% for two-phase nozzles. At small nozzle area ratios, accuracies between theoretical and experimental are better; approximately 5%. All predicted velocities are higher than measured experimental values due to estimation of the drop size and the initial kinetic energy of the liquid at injection point.

It would be desirable to develop a drop size subroutine to better estimate varying drop size. The experimental system can be improved by velocity measurement devices at the inlet. Input of the gas and liquid velocities are necessary in the dual-phase two-component program and thus these measurement devices are vital for better accuracy.

Due to the insensitivity of the pressure distribution, it appears that any reasonable approximation to the pressure profile can be employed in the two-phase two-component flow program. For a given nozzle exit area and inlet pressure, a pressure distribution curve can be obtained through the experimental system. This distribution can therefore be used to obtain good results.

APPENDIX A: SAMPLE P(X) PROGRAM

```

1  $JOB
2  REAL P(75),X(75),PX,FX
3  INTEGER N,K,NP1,NX
4  A=35.3654923
5  B=5.6858E777
6  C=14.39
7  D=0.04731
8  E=.4448C2
9  NX=75
10 PI=35.0
11 P2=8.0
12 PREF=8.0
13 XREF=1C.0
14 N=74
15 NP1=N+1
16 PX=(PI-P2)/380
17 CC 10 K=1,N
18 X(K)=7.7*(K-1)/(N-1)
19 DX=7.7-X(K)
20 IF (X(K).LE.0.7) P(K)=P2+PX*E*(855-A*(X(K)+.5)**B)
21 IF (X(K).GT.0.7) P(K)=P2+PX*E*(C*DX+D*DX**4.9)
22 IF (K.EQ.1) GO TO 1C
23 FRAC=(P(K-1)-PREF)/(P(K-1)-P(K))
24 IF (FRAC.GE.0.0.AND.FPAC.LE.1) XXREF=X(K-1)+FRAC*(X(K)-X(K-1))
25
26 10 CONTINUE
27 FX=XREF/XXREF
28 DO 15 K=1,N
29 X(K)=FX*X(K)
30 P(NP1)=1E5
31 CC 20 K=1,75,3
32 WRITE(6,100)P(K),X(K),P(K+1),X(K+1),P(K+2),X(K+2)
33
34 100 STOP
35 FORMAT(6E12.6)
36 END

```


APPENDIX B: SAMPLE HEAT CAPACITY PROGRAM

```

4JCB      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
1         D6,D7,D8,D9,M,K
          INTEGER N,J,I,C,K,X
          DATA PRESS/0.01,0.4,7.1,0.4,0.7,0.10,0.40,0.70,0.0/
          READ (5,100)((TABLE(J,I),I=1,10),J=1,10)
          CC 10 N=1,9
              PRESS(N)=PRESS(N)+14.696
          CCNTINUE
          CC 20 J=1,16
              CC 30 I=2,10
                  TABLE(J,I)=TABLE(J,I)*.0685590
              CCNTINUE
          CCNTINUE
          N=C.0
          CC 91 J=1,16
              TEMP(J)=400.0 +M
              N=M+10.0
              K=C.0
              CC 90 I=1,11
                  P(I)=K
                  N=1
                  Q=N+1
                  W=100.0+W
                  IF (ABS(TEMP(J)-TABLE(N,1)).GT .001) GO TO 25
                  Q=C
                  GC TC 50
          CONTINUE
          IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
1         1
              GC TC 50
                  N=1+N
                  Q=N+1
                  GC TC 15
          CONTINUE
          K=2
          X=K+1
          IF (P(I).GT. .0001)GO TO 49
              X=C
              GC TC 60
          50
    
```



```

45 IF (ABS(P(I) - PRESS(K)) .GT. .001) GO TC 55
   X=C
   GC TC 60
55 CONTINUE
   IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GC TC 60
   K=1+K
   X=X+1
   GC TC 55
60 CONTINUE
   IF ((C.NE. C) .OR. (X .NE. G)) GO TC 61
   ANS(I)=TABLE(N,K)
   GC TC 90
61 CONTINUE
   IF (C .NE. C) GO TO 63
   D1 = TABLE(N,K) - TABLE(N,X)
   D7 = PRESS(K-1) - PRESS(X-1)
   D8 = PRESS(K-1) - P(I)
   D9 = (D8/D7)*D1
   ANS(I)=C9+TABLE(N,K)
   GC TO 90
62 CONTINUE
   IF (X.NE. C) GO TO 70
   D1 = (TABLE(N,K) - TABLE(Q,K))
   D3 = TABLE(N,1) - TABLE(C,1)
   D4 = TABLE(N,1) - TEMP(J)
   D5 = (D4/D3)*D1
   ANS(I) = C9 + (TABLE(N,K))
   GC TC 90
70 CONTINUE
   D1 = TABLE(N,K) - TABLE(Q,K)
   D2 = TABLE(N,X) - TABLE(Q,X)
   D3 = TABLE(N,1) - TABLE(Q,1)
   D4 = TABLE(N,1) - TEMP(J)

```



```

55 CONTINUE
   IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
   K=J+K
   X=X+1
   GO TO 55
60 CONTINUE
   IF ((C.NE. 0) .OR. (X .NE. 0)) GO TO 61
   ANS(I)=TABLE(N,K)
   GO TO 50
61 CONTINUE
   IF (C.NE. 0) GO TO 63
   D1 = (TABLE(N,K)-TABLE(N,X))
   D7 = (PRESS(K-1)-PRESS(X-1))
   D8 = PRESS(K-1)-P(I)
   D9 = ABS((C8/D7)*D1)
   ANS(I)=D9+TABLE(N,K)
   GO TO 50
62 CONTINUE
   IF (C.NE. 0) GO TO 70
   D1 = (TABLE(N,K)-TABLE(Q,K))
   D3 = TABLE(N,1)-TABLE(Q,1)
   D4 = TABLE(N,1)-TEMP(J)
   D5 = ABS((C4/D3)*D1)
   ANS(I) = (TABLE(N,K))-D9
   GO TO 50
70 CONTINUE
   D1 = TABLE(N,K)-TABLE(Q,K)
   D2 = TABLE(N,X)-TABLE(Q,X)
   D3 = TABLE(N,1)-TABLE(Q,1)
   D4 = TABLE(N,1)-TEMP(J)

```


APPENDIX D: SAMPLE PROPERTY TABLE

SENTRY							
400.0							
0.0	.2484	100.0	.2514	200.0	.2571	CAG	0010
300.0	.2626	400.0	.2678	500.0	.2730	CAG	0020
600.0	.2779	700.0	.2842	800.0	.2962	CAG	0030
900.0	.3003	1000.0	.3065		1.25	1.25CAG	0040
410.0							
0.0	.2484	100.0	.2532	200.0	.2569	CAG	0050
300.0	.2621	400.0	.2672	500.0	.2721	CAG	0060
600.0	.2769	700.0	.2827	800.0	.2918	CAG	0070
900.0	.2976	1000.0	.3030		1.25	1.25CAG	0080
420.0							
0.0	.2484	100.0	.2531	200.0	.2576	CAG	0090
300.0	.2616	400.0	.2665	500.0	.2712	CAG	0100
600.0	.2758	700.0	.2815	800.0	.2894	CAG	0110
900.0	.2950	1000.0	.3000		1.25	1.25CAG	0120
430.0							
0.0	.2484	100.0	.2529	200.0	.2564	CAG	0130
300.0	.2612	400.0	.2659	500.0	.2704	CAG	0140
600.0	.2749	700.0	.2801	800.0	.2869	CAG	0150
900.0	.2924	1000.0	.2970		1.25	1.25CAG	0160
440.0							
0.0	.2484	100.0	.2527	200.0	.2561	CAG	0170
300.0	.2607	400.0	.2651	500.0	.2695	CAG	0180
600.0	.2737	700.0	.2787	800.0	.2847	CAG	0190
900.0	.2898	1000.0	.2942		1.25	1.25CAG	0200
450.0							
0.0	.2484	100.0	.2526	200.0	.2559	CAG	0210
300.0	.2602	400.0	.2645	500.0	.2686	CAG	0220
600.0	.2726	700.0	.2774	800.0	.2825	CAG	0230
900.0	.2872	1000.0	.2915		1.25	1.25CAG	0240
460.0							
0.0	.2484	100.0	.2524	200.0	.2556	CAG	0250
300.0	.2597	400.0	.2638	500.0	.2678	CAG	0260
600.0	.2716	700.0	.2759	800.0	.2804	CAG	0270

900.0	.2848	1000.0	.2833	1.E5	1.E5	CAG	0350
470.0						CAG	0360
0.0	.2484	100.0	.2522	270.0	.2554	CAG	0370
300.0	.2594	400.0	.2631	500.0	.2668	CAG	0380
600.0	.2706	700.0	.2746	800.0	.2786	CAG	0390
900.0	.2826	1000.0	.2863	1.E5	1.E5	CAG	0400
+.480000E+03						CAG	0410
+.600000E+00	+.248400E-00	+.100000E+03	+.252200E-00	+.277000E+03	+.255200E-00	CAG	0420
+.300000E+03	+.258300E-00	+.400000E+03	+.263500E-00	+.500000E+03	+.266000E-00	CAG	0430
+.600000E+01	+.269500E-00	+.700000E+03	+.273200E-00	+.800000E+03	+.276700E-00	CAG	0440
+.400000E+03	+.280500E-00	+.100000E+04	+.284100E-00	+.100000E+06	+.100000E+06	CAG	0450
+.400000E+03						CAG	0460
+.300000E-10	+.248400E-00	+.100000E+03	+.251700E-00	+.270000E+03	+.254900E-00	CAG	0470
+.300000E+03	+.258300E-00	+.400000E+03	+.261700E-00	+.500000E+03	+.265000E-00	CAG	0480
+.800000E+03	+.263400E-00	+.700000E+03	+.271700E-00	+.800000E+03	+.275200E-00	CAG	0490
+.900000E+03	+.274500E-00	+.100000E+04	+.281800E-00	+.100000E+06	+.100000E+06	CAG	0500
+.500000E+03						CAG	0510
+.700000E+00	+.248400E+00	+.100000E+03	+.251700E+00	+.270000E+03	+.254700E+00	CAG	0520
+.700000E+03	+.257800E+00	+.400000E+03	+.261000E+00	+.500000E+03	+.264200E+00	CAG	0530
+.600000E+03	+.267300E+00	+.700000E+03	+.273500E+00	+.800000E+03	+.277000E+00	CAG	0540
+.900000E+03	+.276800E+00	+.100000E+04	+.283000E+00	+.100000E+06	+.100000E+06	CAG	0550
+.510000E+03						CAG	0560
+.000000E+00	+.248400E+00	+.100000E+03	+.251600E+00	+.270000E+03	+.254400E+00	CAG	0570
+.300000E+03	+.257300E+00	+.400000E+03	+.261400E+00	+.500000E+03	+.263300E+00	CAG	0580
+.600000E+03	+.266400E+00	+.700000E+03	+.271400E+00	+.800000E+03	+.272400E+00	CAG	0590
+.900000E+03	+.275400E+00	+.100000E+04	+.279300E+00	+.100000E+06	+.100000E+06	CAG	0600
+.520000E+03						CAG	0610
+.000000E+00	+.248400E+00	+.100000E+03	+.251400E+00	+.270000E+03	+.254200E+00	CAG	0620
+.300000E+03	+.256000E+00	+.400000E+03	+.261300E+00	+.500000E+03	+.262000E+00	CAG	0630
+.600000E+03	+.265000E+00	+.700000E+03	+.271300E+00	+.800000E+03	+.271200E+00	CAG	0640
+.900000E+03	+.274000E+00	+.100000E+04	+.275300E+00	+.100000E+06	+.100000E+06	CAG	0650
+.530000E+03						CAG	0660
+.000000E+00	+.248400E+00	+.100000E+03	+.251300E+00	+.270000E+03	+.253900E+00	CAG	0670
+.300000E+03	+.256500E+00	+.400000E+03	+.261100E+00	+.500000E+03	+.261000E+00	CAG	0680
+.600000E+03	+.265400E+00	+.700000E+03	+.271200E+00	+.800000E+03	+.270100E+00	CAG	0690
+.900000E+03	+.274400E+00	+.100000E+04	+.275500E+00	+.100000E+06	+.100000E+06	CAG	0700
+.540000E+03						CAG	0710
+.000000E+00	+.248400E+00	+.100000E+03	+.251100E+00	+.270000E+03	+.253600E+00	CAG	0720
+.300000E+03	+.256100E+00	+.400000E+03	+.260900E+00	+.500000E+03	+.261100E+00	CAG	0730
+.600000E+03	+.265000E+00	+.700000E+03	+.270500E+00	+.800000E+03	+.269100E+00	CAG	0740
+.900000E+03	+.273900E+00	+.100000E+04	+.274200E+00	+.100000E+06	+.100000E+06	CAG	0750
+.550000E+03						CAG	0760
+.000000E+00	+.248400E+00	+.100000E+03	+.250900E+00	+.270000E+03	+.253400E+00	CAG	0770
+.300000E+03	+.255300E+00	+.400000E+03	+.260300E+00	+.500000E+03	+.260700E+00	CAG	0780
+.600000E+03	+.264200E+00	+.700000E+03	+.270700E+00	+.800000E+03	+.269100E+00	CAG	0790
+.900000E+03	+.273000E+00	+.100000E+04	+.271000E+00	+.100000E+06	+.100000E+06	CAG	0800
+.560000E+03						CAG	0810
+.000000E+00	+.248400E+00	+.100000E+03	+.250700E+00	+.270000E+03	+.253200E+00	CAG	0820
+.300000E+03	+.255100E+00	+.400000E+03	+.260100E+00	+.500000E+03	+.260200E+00	CAG	0830
+.600000E+03	+.264000E+00	+.700000E+03	+.270300E+00	+.800000E+03	+.267200E+00	CAG	0840
+.900000E+03	+.272800E+00	+.100000E+04	+.272300E+00	+.100000E+06	+.100000E+06	CAG	0850
+.570000E+03						CAG	0860
+.000000E+00	+.248400E+00	+.100000E+03	+.250500E+00	+.270000E+03	+.253000E+00	CAG	0870
+.300000E+03	+.254900E+00	+.400000E+03	+.259500E+00	+.500000E+03	+.259700E+00	CAG	0880
+.600000E+03	+.263800E+00	+.700000E+03	+.270100E+00	+.800000E+03	+.266400E+00	CAG	0890
+.900000E+03	+.272600E+00	+.100000E+04	+.271800E+00	+.100000E+06	+.100000E+06	CAG	0900
+.000000E+00						CAG	0910
+.300000E+00	+.460000E+00	+.100000E+04	+.460000E+00	+.100000E+06	+.100000E+06	CAG	0920
+.100000E+04	+.100000E+01					CAG	0930
+.000000E+00	+.460000E+00	+.100000E+04	+.460000E+00	+.100000E+06	+.100000E+06	CAG	0940
400.0						CAG	0950
0.0	28.010	100.0	28.010	200.0	28.010	CAG	0960
300.0	28.540	400.0	28.540	500.0	28.540	CAG	0970
600.0	29.070	700.0	29.070	800.0	29.070	CAG	0980
900.0	29.600	1000.0	29.600	1.E5	1.E5	CAG	0990
410.0						CAG	1000
0.0	28.010	100.0	28.010	200.0	28.010	CAG	1010
300.0	28.540	400.0	28.540	500.0	28.540	CAG	1020
600.0	29.070	700.0	29.070	800.0	29.070	CAG	1030
900.0	29.600	1000.0	29.600	1.E5	1.E5	CAG	1040
420.0						CAG	1050
0.0	28.010	100.0	28.010	200.0	28.010	CAG	1060

300.0	28.508	400.0	28.710	500.0	28.942	WAG	1070
600.0	29.055	700.0	29.242	800.0	29.331	WAG	1080
900.0	29.460	1000.0	29.630		1.85	1.85 WAG	1090
430.0						WAG	1100
0.0	28.010	100.0	28.175	200.0	28.310	WAG	1110
300.0	28.472	400.0	28.558	500.0	28.653	WAG	1120
600.0	28.958	700.0	29.147	800.0	29.200	WAG	1130
900.0	29.312	1000.0	29.425		1.85	1.85 WAG	1140
440.0						WAG	1150
0.0	28.010	100.0	28.153	200.0	28.284	WAG	1160
300.0	28.436	400.0	28.635	500.0	28.765	WAG	1170
600.0	28.863	700.0	29.012	800.0	29.070	WAG	1180
900.0	29.165	1000.0	29.255		1.85	1.85 WAG	1190
450.0						WAG	1200
0.0	28.010	100.0	28.151	200.0	28.266	WAG	1210
300.0	28.400	400.0	28.543	500.0	28.680	WAG	1220
600.0	28.768	700.0	28.842	800.0	28.940	WAG	1230
900.0	29.020	1000.0	29.090		1.85	1.85 WAG	1240
460.0						WAG	1250
0.0	28.010	100.0	28.140	200.0	28.244	WAG	1260
300.0	28.363	400.0	28.442	500.0	28.545	WAG	1270
600.0	28.677	700.0	28.750	800.0	28.817	WAG	1280
900.0	28.880	1000.0	28.940		1.85	1.85 WAG	1290
470.0						WAG	1300
0.0	28.010	100.0	28.123	200.0	28.222	WAG	1310
300.0	28.327	400.0	28.422	500.0	28.517	WAG	1320
600.0	28.587	700.0	28.648	800.0	28.700	WAG	1330
900.0	28.750	1000.0	28.770		1.85	1.85 WAG	1340
480.0						WAG	1350
0.00000E+00	280100E+02	100000E+03	281160E+02	200000E+03	282100E+02	WAG	1360
0.00000E+00	282150E+02	400000E+03	283750E+02	500000E+03	284460E+02	WAG	1370
0.00000E+00	285040E+02	700000E+03	285520E+02	800000E+03	285900E+02	WAG	1380
0.00000E+00	286270E+02	100000E+04	285140E+02	100000E+05	100000E+06	WAG	1390
0.00000E+00	280100E+02	100000E+03	281104E+02	200000E+03	281870E+02	WAG	1400
0.00000E+00	282250E+02	400000E+03	281180E+02	500000E+03	281730E+02	WAG	1420
0.00000E+00	284240E+02	700000E+03	281560E+02	800000E+03	281480E+02	WAG	1430
0.00000E+00	285130E+02	100000E+04	281580E+02	100000E+05	100000E+06	WAG	1440
0.00000E+00	280100E+02	100000E+03	281520E+02	200000E+03	281550E+02	WAG	1450
0.00000E+00	282150E+02	400000E+03	282680E+02	500000E+03	281130E+02	WAG	1460
0.00000E+00	283500E+02	700000E+03	281550E+02	800000E+03	281360E+02	WAG	1480
0.00000E+00	284120E+02	100000E+04	284240E+02	100000E+05	100000E+06	WAG	1490
0.00000E+00	280100E+02	100000E+03	284380E+02	200000E+03	281320E+02	WAG	1510
0.00000E+00	281340E+02	400000E+03	283220E+02	500000E+03	282530E+02	WAG	1520
0.00000E+00	282820E+02	700000E+03	283280E+02	800000E+03	281130E+02	WAG	1530
0.00000E+00	283200E+02	100000E+04	283300E+02	100000E+05	100000E+06	WAG	1540
0.00000E+00	280100E+02	100000E+03	283680E+02	200000E+03	281120E+02	WAG	1550
0.00000E+00	281500E+02	400000E+03	281100E+02	500000E+03	281200E+02	WAG	1560
0.00000E+00	282200E+02	700000E+03	282100E+02	800000E+03	281350E+02	WAG	1580
0.00000E+00	282350E+02	100000E+04	282350E+02	100000E+05	100000E+06	WAG	1590
0.00000E+00	280100E+02	100000E+03	282580E+02	200000E+03	281500E+02	WAG	1600
0.00000E+00	281200E+02	400000E+03	281430E+02	500000E+03	281560E+02	WAG	1620
0.00000E+00	281640E+02	700000E+03	281680E+02	800000E+03	281630E+02	WAG	1630
0.00000E+00	281560E+02	100000E+04	281480E+02	100000E+05	100000E+06	WAG	1640
0.00000E+00	281100E+02	100000E+03	282480E+02	200000E+03	280700E+02	WAG	1650
0.00000E+00	280920E+02	400000E+03	281080E+02	500000E+03	281140E+02	WAG	1670
0.00000E+00	281120E+02	700000E+03	281100E+02	800000E+03	280960E+02	WAG	1680
0.00000E+00	280800E+02	100000E+04	283640E+02	100000E+05	100000E+06	WAG	1690
0.00000E+00	280100E+02	100000E+03	283400E+02	200000E+03	280550E+02	WAG	1700
0.00000E+00	280680E+02	400000E+03	283750E+02	500000E+03	280730E+02	WAG	1710
0.00000E+00	280560E+02	700000E+03	283540E+02	800000E+03	280350E+02	WAG	1720
0.00000E+00	280150E+02	100000E+04	283920E+02	100000E+05	100000E+06	WAG	1740
0.00000E+00	280100E+02	100000E+03	283320E+02	200000E+03	280440E+02	WAG	1760
0.00000E+00	280480E+02	400000E+03	283430E+02	500000E+03	280360E+02	WAG	1770
0.00000E+00	280260E+02	700000E+03	280040E+02	800000E+03	280980E+02	WAG	1780

400.0	4.33	410.0	4.33	420.0	4.33	VIAL 2510
430.0	4.33	440.0	4.33	450.0	4.33	VIAL 2520
460.0	4.33	470.0	4.33	480.0	4.33	VIAL 2530
+.492000E+03	+.433000E+01	+.500000E+03	+.374000E+01	+.510000E+03	+.316000E+01	VIAL 2540
+.520000E+03	+.272000E+01	+.510000E+03	+.247000E+01	+.540000E+03	+.204000E+01	VIAL 2550
+.550000E+03	+.195000E+01	+.560000E+03	+.165000E+01	+.570000E+03	+.150000E+01	VIAL 2560
+.100000E+06	+.100000E+06					VIAL 2570
+.492000E+03	+.433000E+01	+.500000E+03	+.374000E+01	+.510000E+03	+.316000E+01	VIAL 2580
+.520000E+03	+.272000E+01	+.510000E+03	+.247000E+01	+.540000E+03	+.204000E+01	VIAL 2590
+.550000E+03	+.195000E+01	+.560000E+03	+.165000E+01	+.570000E+03	+.150000E+01	VIAL 2600
+.100000E+06	+.100000E+06					VIAL 2610
400.0	.03445	410.0	.03575	420.0	.03588	VIAL 2620
430.0	.03630	440.0	.03673	450.0	.03755	VIAL 2630
460.0	.03718	470.0	.03810	480.0	.03943	VIAL 2640
490.0	.04005	500.0	.04205	510.0	.04330	VIAL 2650
520.0	.04199	530.0	.04255	540.0	.04315	VIAL 2660
550.0	.04375	560.0	.04435	570.0	.04495	VIAL 2670
1.	+ 51.	+5				VIAL 2680
400.0	.01900	410.0	.01940	420.0	.01980	VIAL 2690
430.0	.02020	440.0	.02050	450.0	.02100	VIAL 2700
460.0	.02145	470.0	.02190	480.0	.02235	VIAL 2710
+.492000E+01	+.232000E-01	+.500000E+03	+.234000E-01	+.510000E+03	+.237500E-01	VIAL 2720
+.520000E+03	+.241000E-01	+.510000E+03	+.245000E-01	+.540000E+03	+.249000E-01	VIAL 2730
+.550000E+03	+.253000E-01	+.560000E+03	+.258000E-01	+.570000E+03	+.262500E-01	VIAL 2740
+.100000E+06	+.100000E+06					VIAL 2750
+.492000E+03	+.756000E+02	+.510000E+03	+.725000E+02	+.550000E+03	+.708000E+02	SIG 2760
+.570000E+03	+.640000E+02	+.100000E+06	+.100000E+06			SIG 2770

APPENDIX E: SAMPLE INPUT DATA

APRIL 15, 1980	1	NOZZLE D, 2 MPA	920	1
-0.3	0	0.0	208.0	
1010.0	20.0	28.02	20.0	
20.0	0.05	537.0	0.1	
10	0.05	0.0004		
IN. NCZZL				
250.0	000000	138144+00	288590+03	276288+00
286616+03	414432+00	552576+00	276898+03	690720+00
266555+03	628864+00	967008+00	36879+03	110515+01
224115+03	124330+01	138144+01	159229+03	151958+01
183824+03	165773+01	179584+01	161766+03	193402+01
151728+03	207216+01	221030+01	133482+03	24845+01
125216+03	248659+01	262474+01	110251+03	276289+01
103500+03	290102+01	303517+01	913291+02	31771+01
716542+02	321546+01	345360+01	760453+02	359174+01
603065+02	414432+01	386803+01	638046+02	400618+01
513102+02	455875+01	428246+01	540765+02	442061+01
442206+02	497315+01	469690+01	463969+02	482504+01
380527+02	533762+01	511133+01	403611+02	524947+01
342765+02	580205+01	552576+01	356211+02	565391+01
308124+02	621648+01	594019+01	318910+02	607827+01
280228+02	663091+01	635463+01	288931+02	649277+01
257725+02	704525+01	676906+01	264540+02	690720+01
237775+02	745078+01	713249+01	244000+02	732163+01
220446+02	787421+01	754792+01	226935+02	772607+01
204466+02	828864+01	801235+01	209684+02	815053+01
185235+02	870307+01	842679+01	194257+02	856493+01
174360+02	911751+01	884122+01	179296+02	897936+01
159617+02	953194+01	925555+01	164525+02	939379+01
144504+02	994637+01	967008+01	149807+02	980823+01
		100845+02	100000+06	100000+06

APPENDIX F: SAMPLE 140PC CALIBRATION PROGRAM

```

10 DIM X(15,100),Sum(15),Mean(15),Sum2(15),Sd(15)
30 N=10
40 FOR I=1 TO N
50   OUTPUT 709;"AI1VT1"
60   ENTER 709:X(1,I)
70   OUTPUT 709;"AI2VT1"
80   ENTER 709:X(2,I)
90   OUTPUT 709;"AI3VT1"
100  ENTER 709:X(3,I)
110  OUTPUT 709;"AI4VT1"
120  ENTER 709:X(4,I)
130  OUTPUT 709;"AI5VT1"
140  ENTER 709:X(5,I)
150  OUTPUT 709;"AI6VT1"
160  ENTER 709:X(6,I)
170  OUTPUT 709;"AI7VT1"
180  ENTER 709:X(7,I)
190  OUTPUT 709;"AI8VT1"
200  ENTER 709:X(8,I)
210  OUTPUT 709;"AI9VT1"
220  ENTER 709:X(9,I)
230  OUTPUT 709;"AI16VT1"
240  ENTER 709:X(10,I)
250  OUTPUT 709;"AI11VT1"
260  ENTER 709:X(11,I)
261  OUTPUT 709;"AI12VT1"
262  ENTER 709:X(12,I)
263  OUTPUT 709;"AI13VT1"
264  ENTER 709:X(13,I)
267  OUTPUT 709;"AI17VT1"
268  ENTER 709:X(14,I)
270  NEXT I

```



```

280 PRINT "
290 PRINT "
300 !
310 PRINT "
320 PRINT
330 FOR I=1 TO N
340 PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I),X(4,I),X(5,I),X(6,I),X(7,I),
X(8,I)
350 NEXT I
360 PRINT
370 PRINT "
380 PRINT "
390 PRINT "
400 FOR I=1 TO N
410 PRINT USING "DD.DDDD";X(9,I),X(10,I),X(11,I),X(12,I),X(13,I),X(14,I)
411 NEXT I
413 PRINT
414 PRINT "
415 PRINT "
420 PRINT
440 FOR J=1 TO 14
450 Sum(J)=0
460 FOR I=1 TO N
470 Sum(J)=Sum(J)+X(J,I)
480 NEXT I
490 Mean(J)=Sum(J)/N
510 NEXT J
512 FOR J=1 TO 14
513 FOR I=1 TO N
515 Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
516 NEXT I
518 Sd(J)=SQR(Sum2(J)/(N-1))
519 IF J=14 THEN GOTO 523
521 PRINT "channel " "J,Mean(J)," "Sd(J)
522 GOTO 525
523 PRINT "CHANNEL " "J+3,Mean(J)," "Sd(J)
525 NEXT J
526 END

```


THIS DATA IS FOR A PRESSURE OF 0 PSI

CHANNELS							
1	2	3	4	5	6	7	8
1.6588	1.8301	1.7702	1.6914	1.8429	1.7485	1.7900	1.8098
1.6589	1.8305	1.7705	1.6922	1.8431	1.7484	1.7901	1.8101
1.6598	1.8308	1.7715	1.6931	1.8446	1.7500	1.7918	1.8120
1.6605	1.8318	1.7717	1.6935	1.8444	1.7499	1.7916	1.8117
1.6603	1.8317	1.7722	1.6931	1.8446	1.7497	1.7917	1.8117
1.6598	1.8315	1.7716	1.6928	1.8439	1.7495	1.7909	1.8112
1.6596	1.8310	1.7712	1.6925	1.8437	1.7494	1.7909	1.8110
1.6597	1.8310	1.7714	1.6925	1.8441	1.7494	1.7910	1.8112
1.6593	1.8311	1.7712	1.6923	1.8438	1.7496	1.7907	1.8114
1.6594	1.8313	1.7709	1.6927	1.8438	1.7496	1.7906	1.8109

CHANNEL						
9	10	11	12	13	17	
1.7941	1.7381	1.7211	1.8335	-.0119	14.8960	
1.7946	1.7389	1.7221	1.8336	-.0119	14.9000	
1.7961	1.7397	1.7239	1.8353	-.0119	14.9090	
1.7958	1.7400	1.7232	1.8341	-.0119	14.9060	
1.7960	1.7401	1.7237	1.8351	-.0119	14.9030	
1.7957	1.7402	1.7236	1.8347	-.0119	14.9000	
1.7955	1.7388	1.7233	1.8340	-.0119	14.8990	
1.7959	1.7394	1.7226	1.8342	-.0119	14.9020	
1.7958	1.7398	1.7233	1.8338	-.0119	14.9020	
1.7954	1.7394	1.7231	1.8341	-.0119	14.9000	

	MEAN	STANDARD DEVIATION
channel 1	1.65961	.000542524961023
channel 2	1.83108	.000528730134904
channel 3	1.77124	.000587272414548
channel 4	1.69261	.000583952052826
channel 5	1.84389	.000574359546703
channel 6	1.7494	.000537483849887
channel 7	1.79093	.0006254775953
channel 8	1.8111	.000697614984549
channel 9	1.79549	.000647130417905
channel 10	1.73944	.000668663675633
channel 11	1.72299	.000847807630172
channel 12	1.83424	.000607728009338
channel 13	-.0118729	8.1846740246E-6
channel 17	14.9017	.00368329562575

APPENDIX H: SAMPLE 200PC CALIBRATION PROGRAM

```

PRINT "THIS PROGRAM IS USED TO CALIBRATE 100 PSI PRESSURE TRANSDUCERS."
PRINT "ENTER THE AMOUNT OF READINGS YOU WISH THE PROGRAM TO AVERAGE"
DIM X(11,100),Sum(11),Mean(11),Sum2(11),Sd(11)
PRINT
INPUT N
Y=0
FOR I=1 TO 11
PRINT
PRINT
PRINT "THIS RUN IS FOR A PRESSURE OF";Y;"PSI"
PRINT "_____ "
PRINT
PRINT "ONCE THE PRESSURE IS SET AT";Y;"PSI"
PRINT "PUSH THE CONTINUE BUTTON AND WAIT FOR DATA."
Y=Y+10
PAUSE
FOR I=1 TO N
OUTPUT 709;"AI12VT1"
ENTER 709;X(1,I)
OUTPUT 709;"AI14VT1"
ENTER 709;X(2,I)
OUTPUT 709;"AI15VT1"
ENTER 709;X(3,I)
NEXT I

```

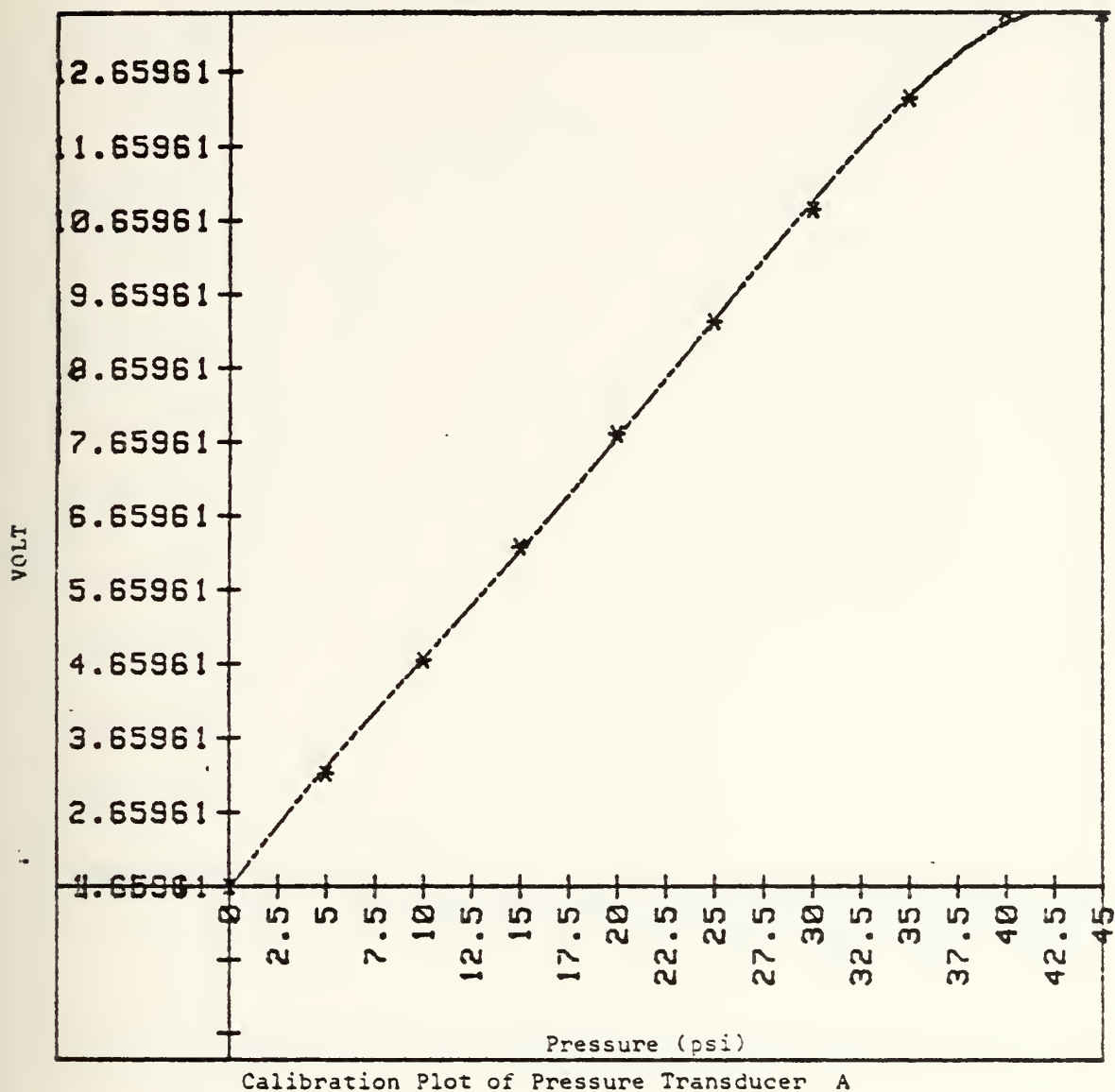


```

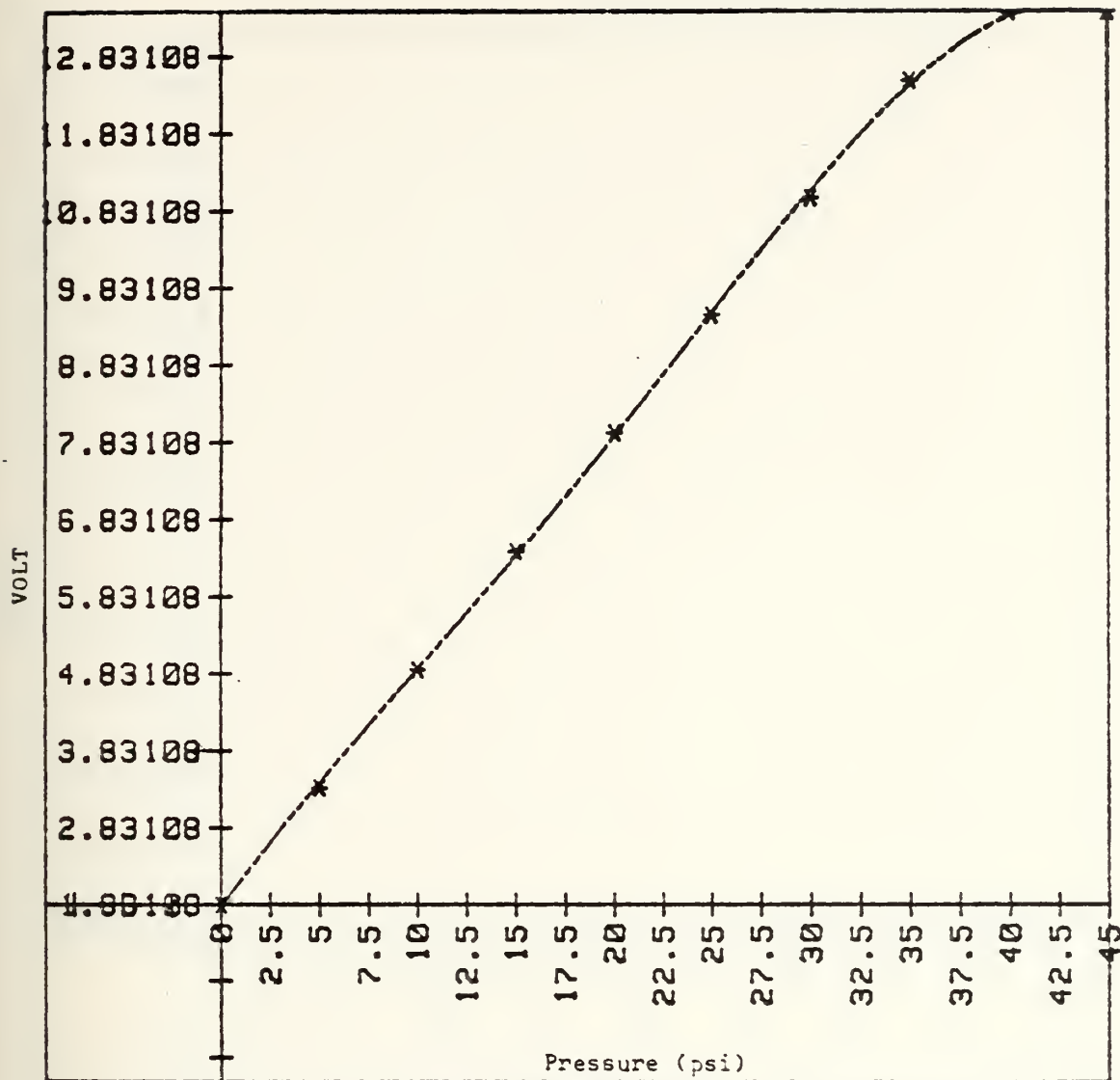
PRINT "
PRINT "
PRINT "
PRINT "
FOR I=1 TO N
PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I)
NEXT I
PRINT "
PRINT "
PRINT "
PRINT "
FOR J=1 TO 3
Sum(J)=0
FOR I=1 TO N
Sum(J)=Sum(J)+X(J,I)
NEXT I
Mean(J)=Sum(J)/N
NEXT J
FOR J=1 TO 3
FOR I=1 TO N
Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
NEXT I
Sd(J)=SQR(Sum2(J)/(N-1))
PRINT "channel ";J,Mean(J)," ",Sd(J)
NEXT J
PRINT
PRINT
PRINT
PRINT
NEXT J
END

```

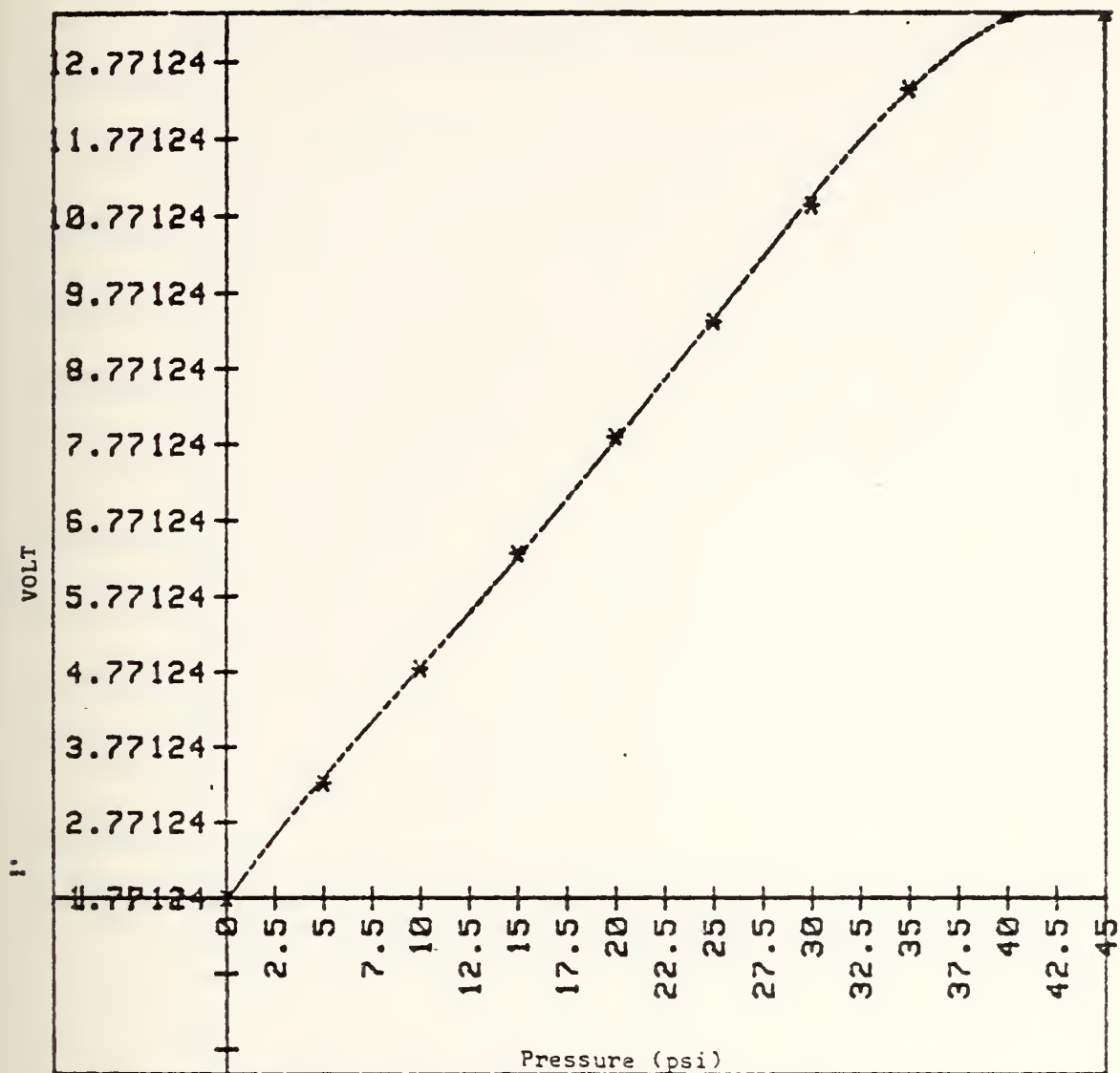

APPENDIX I: CALIBRATION PLOT OF PRESSURE TRANSDUCERS



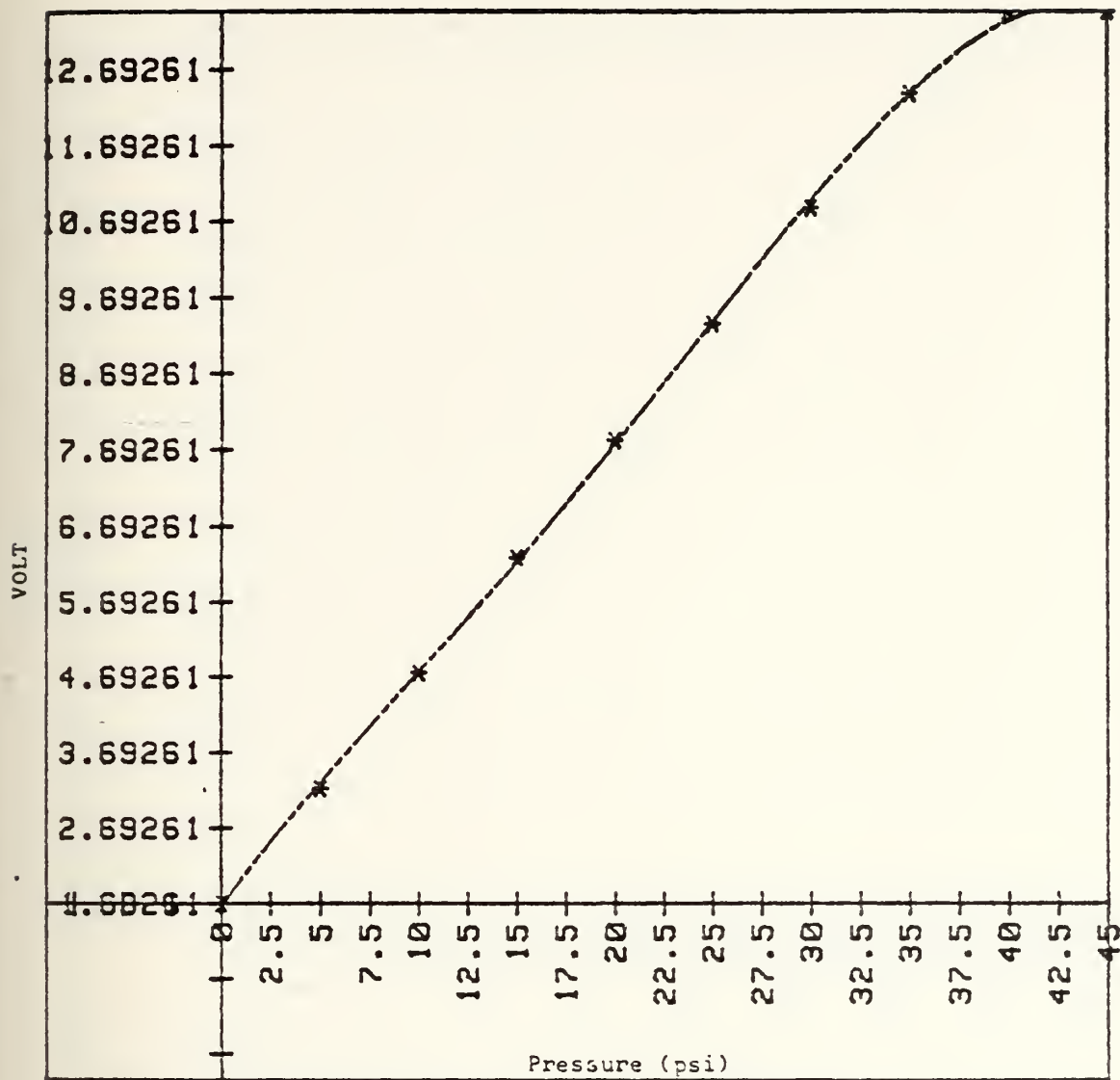
Calibration Plot of Pressure Transducer A



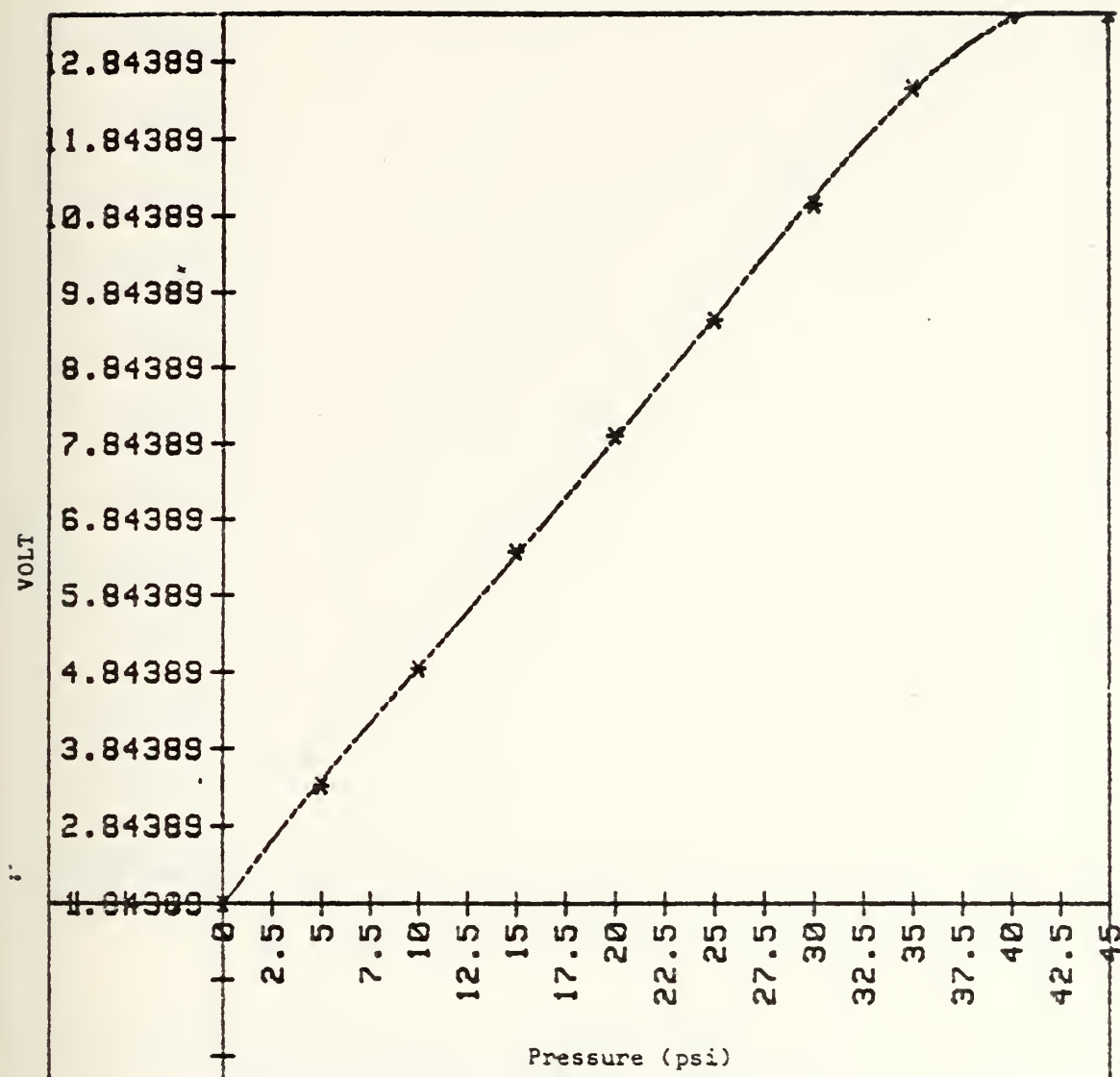
Calibration Plot of Pressure Transducer B



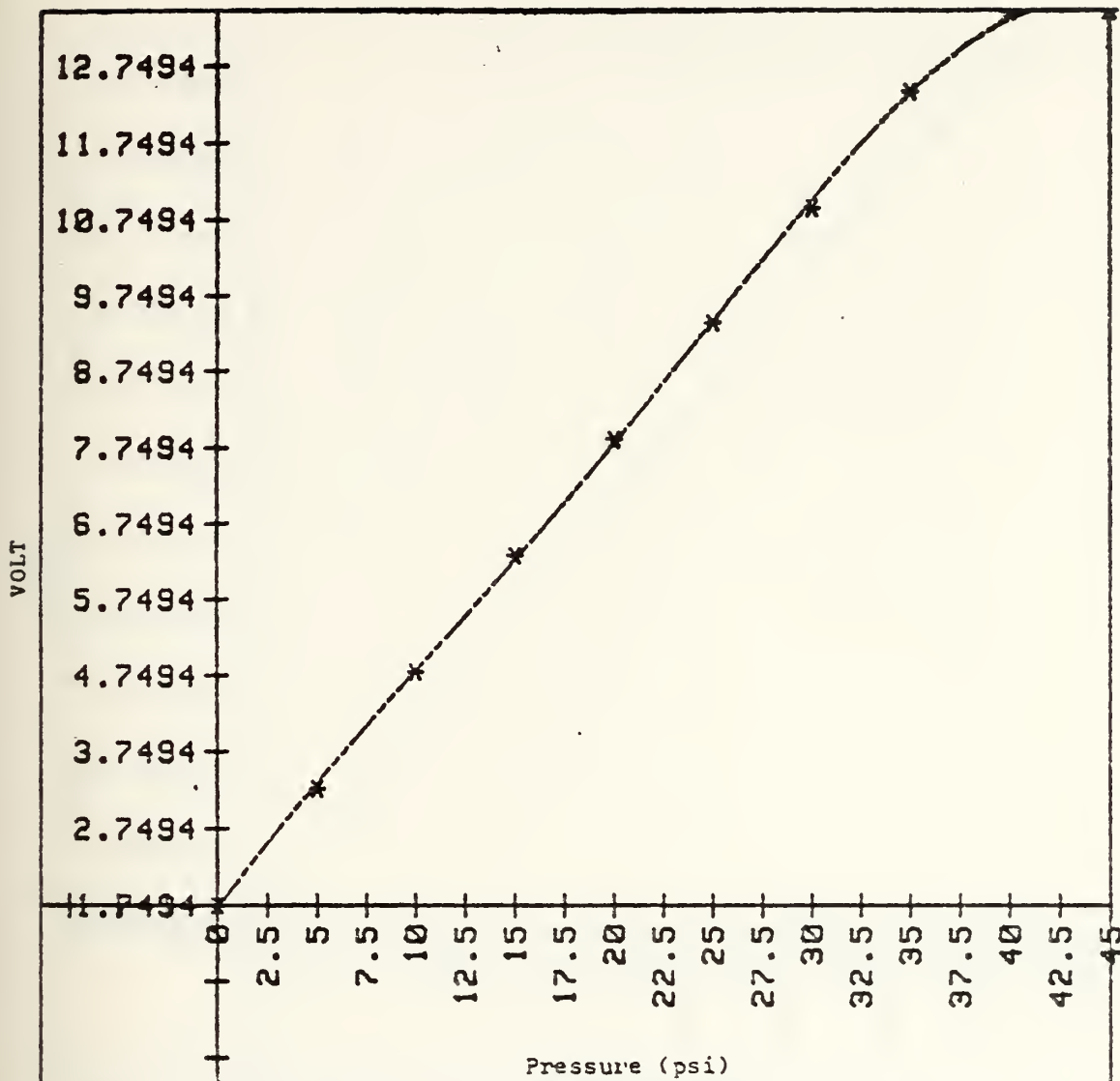
Calibration Plot of Pressure Transducer C



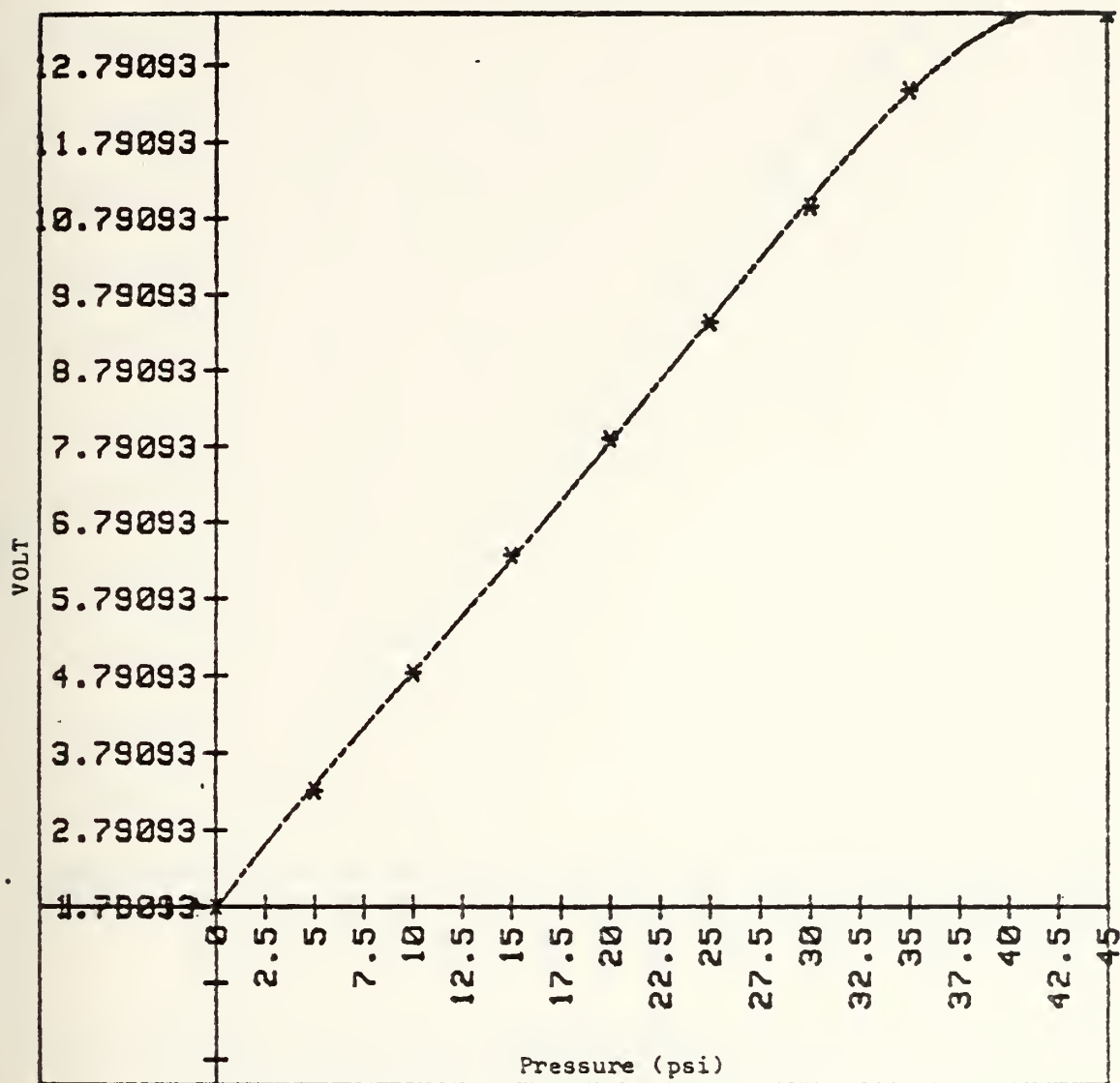
Calibration Plot of Pressure Transducer D



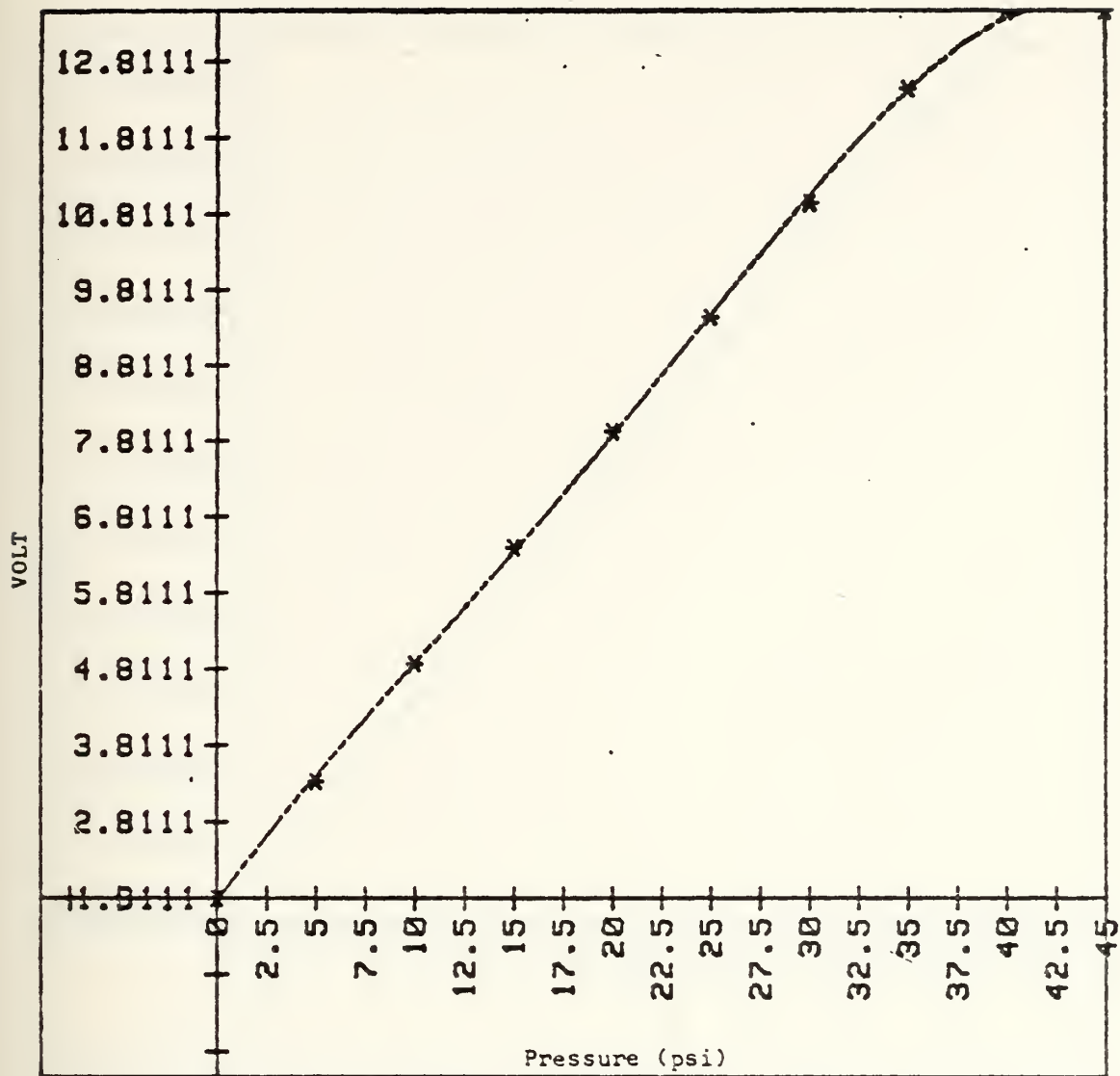
Calibration Plot of Pressure Transducer E



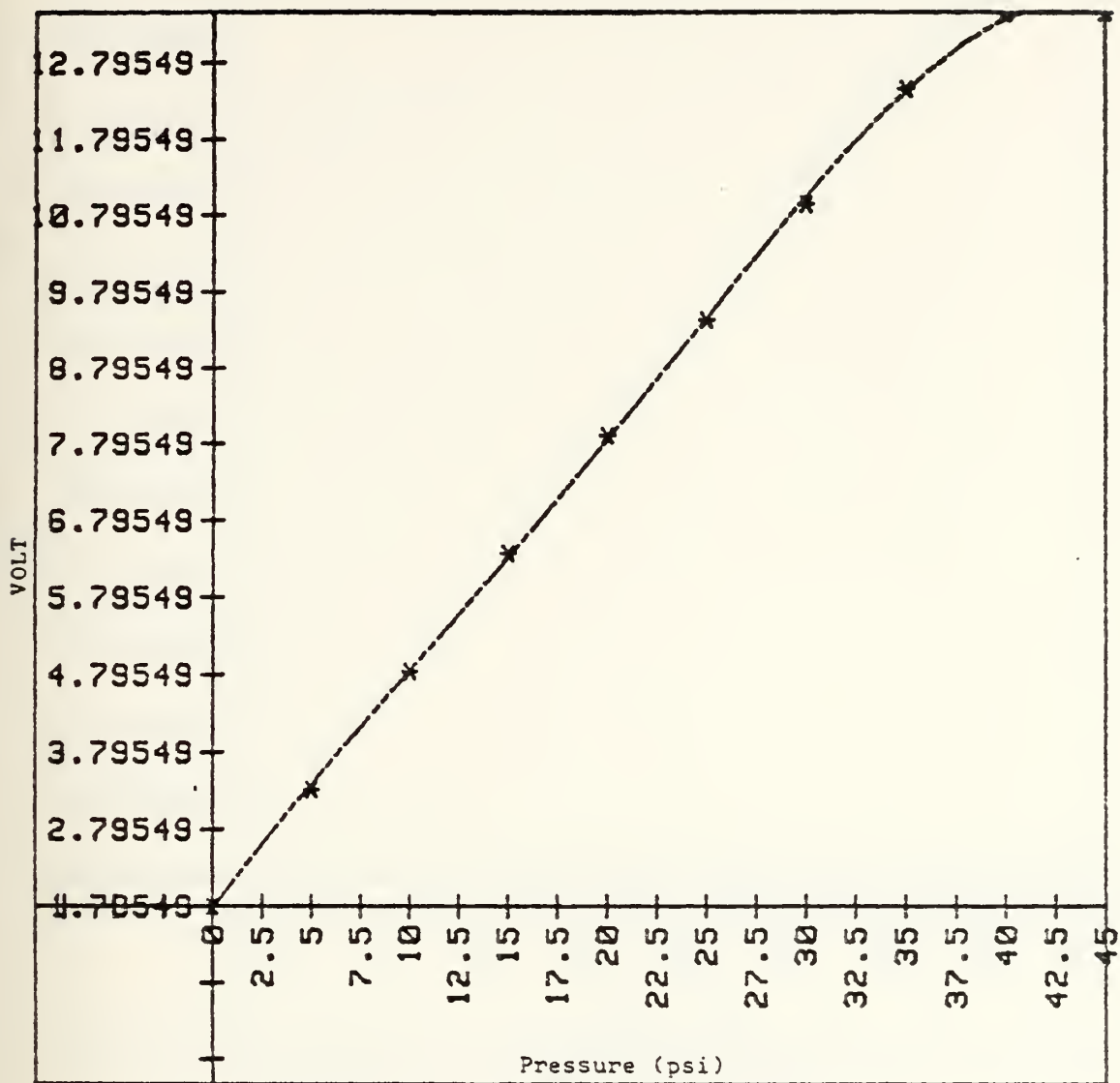
Calibration Plot of Pressure Transducer F



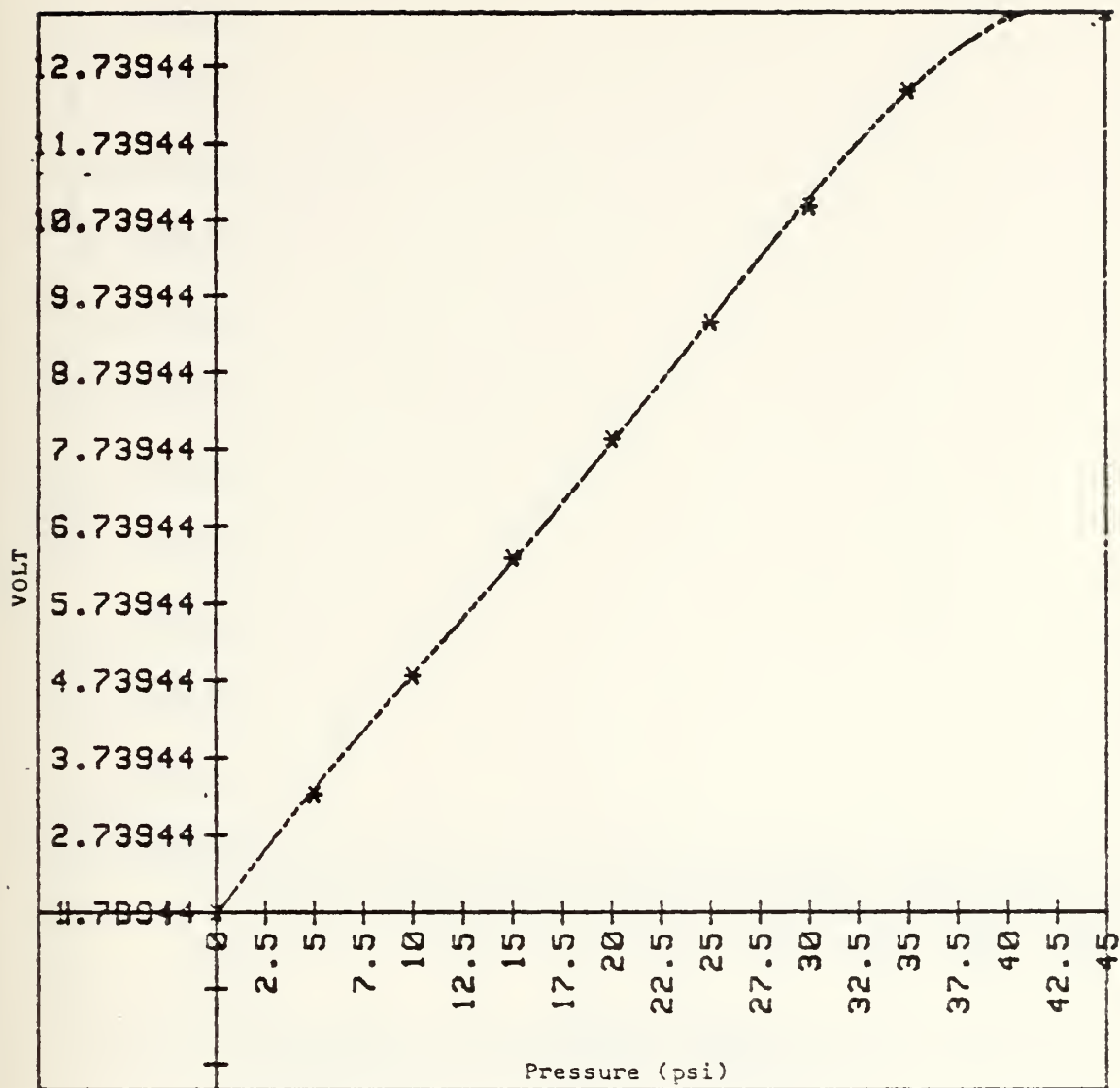
Calibration Plot of Pressure Transducer G



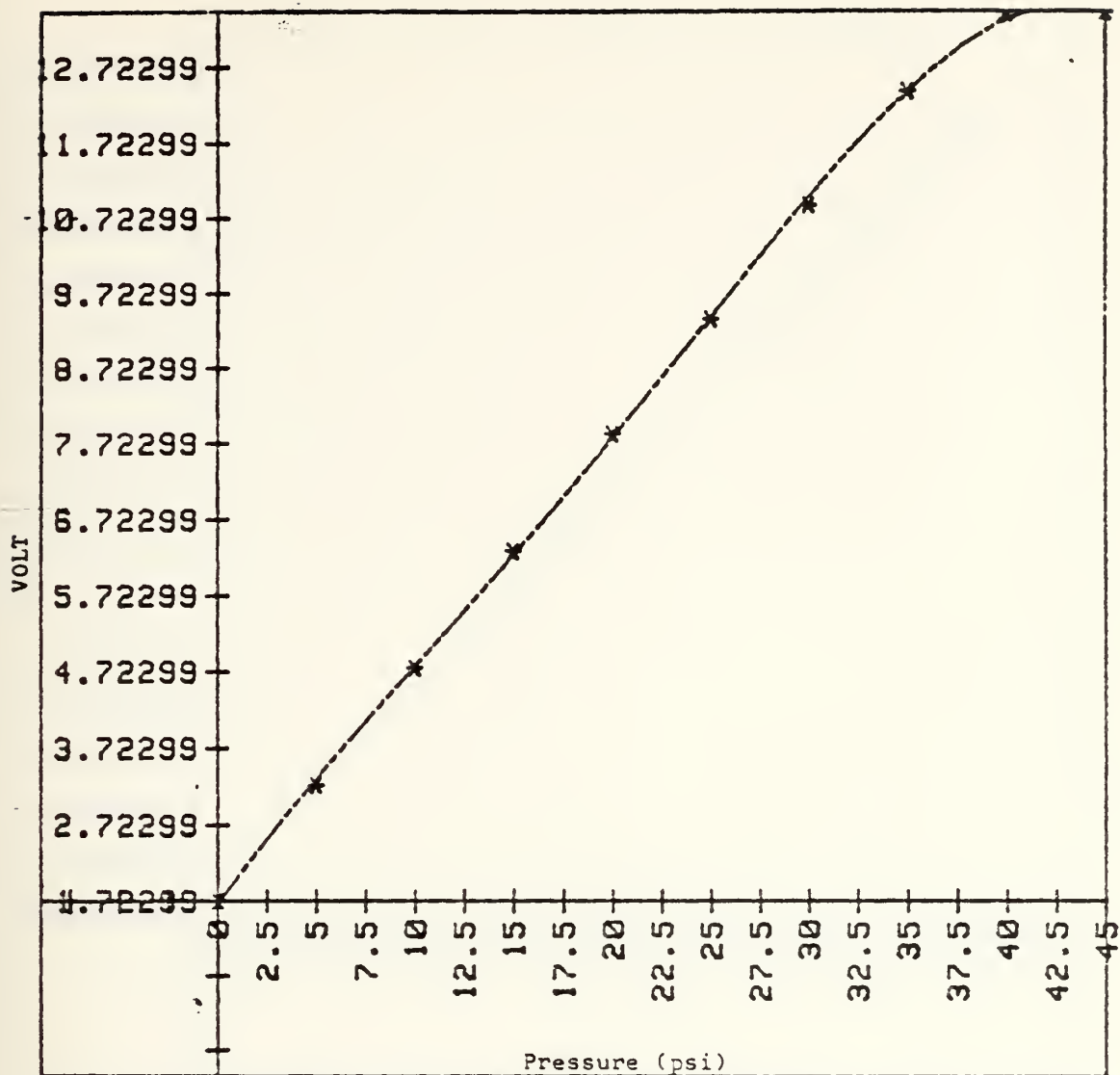
Calibration Plot of Pressure Transducer H



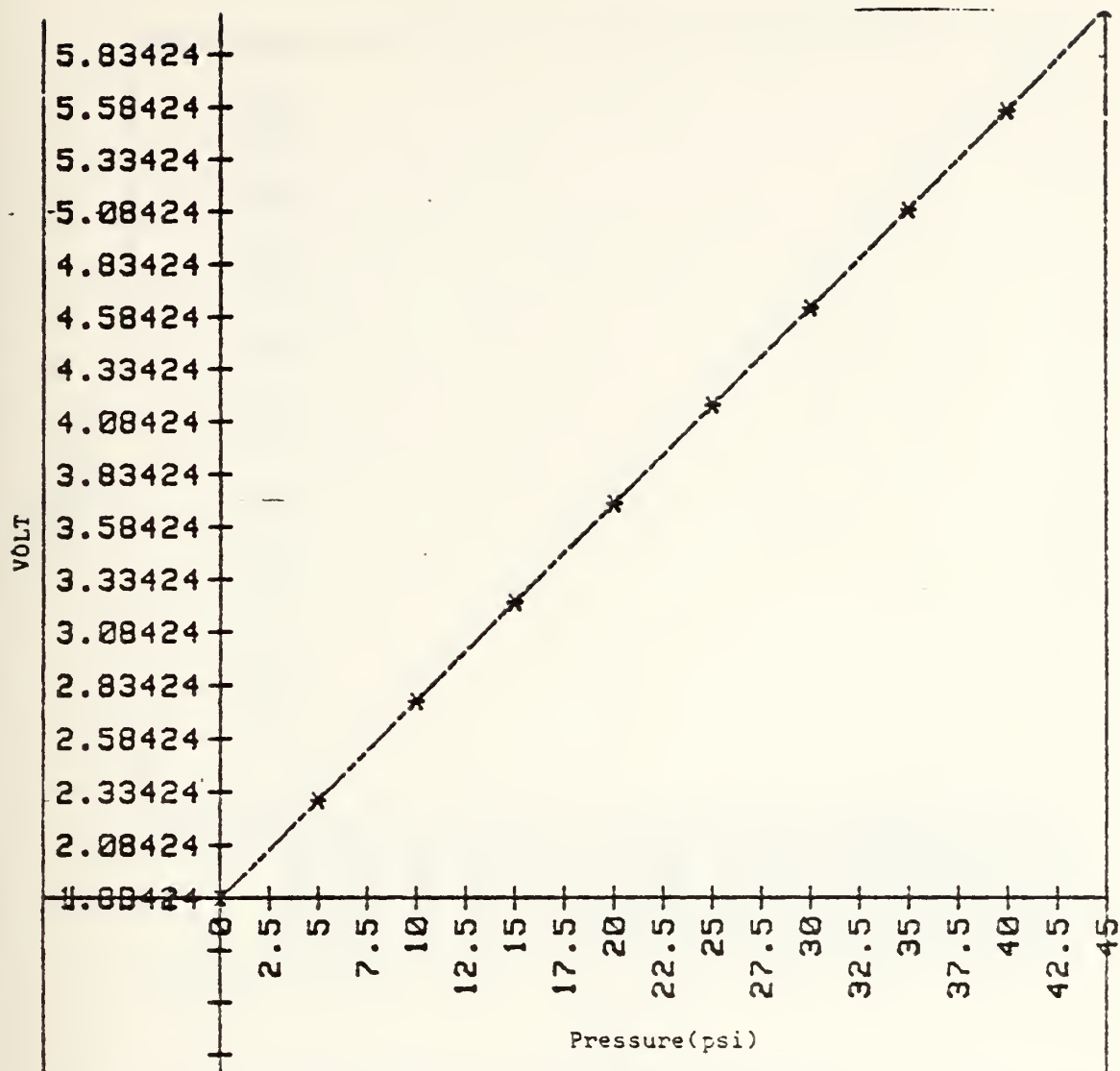
Calibration Plot of Pressure Transducer I



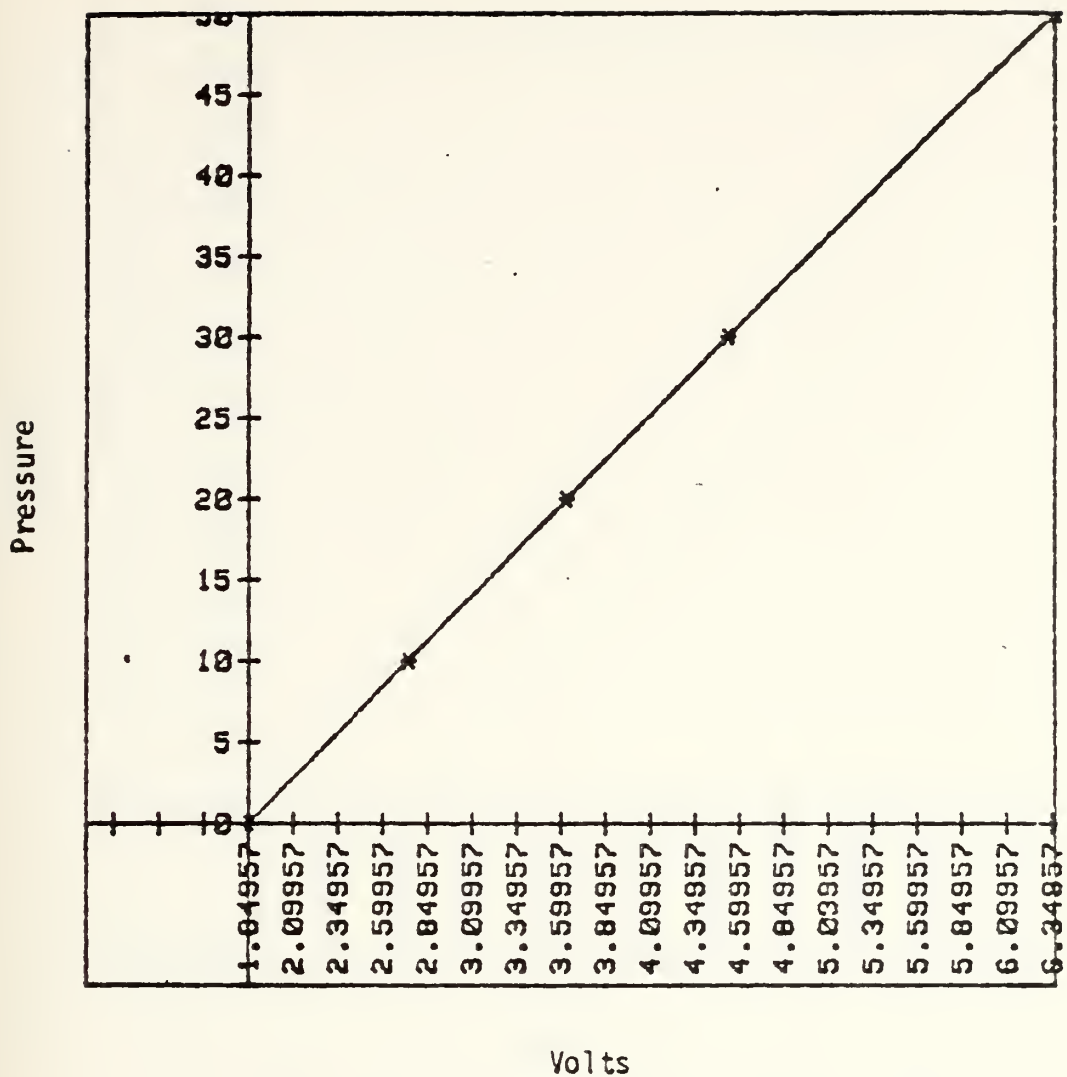
Calibration Plot of Pressure Transducer J



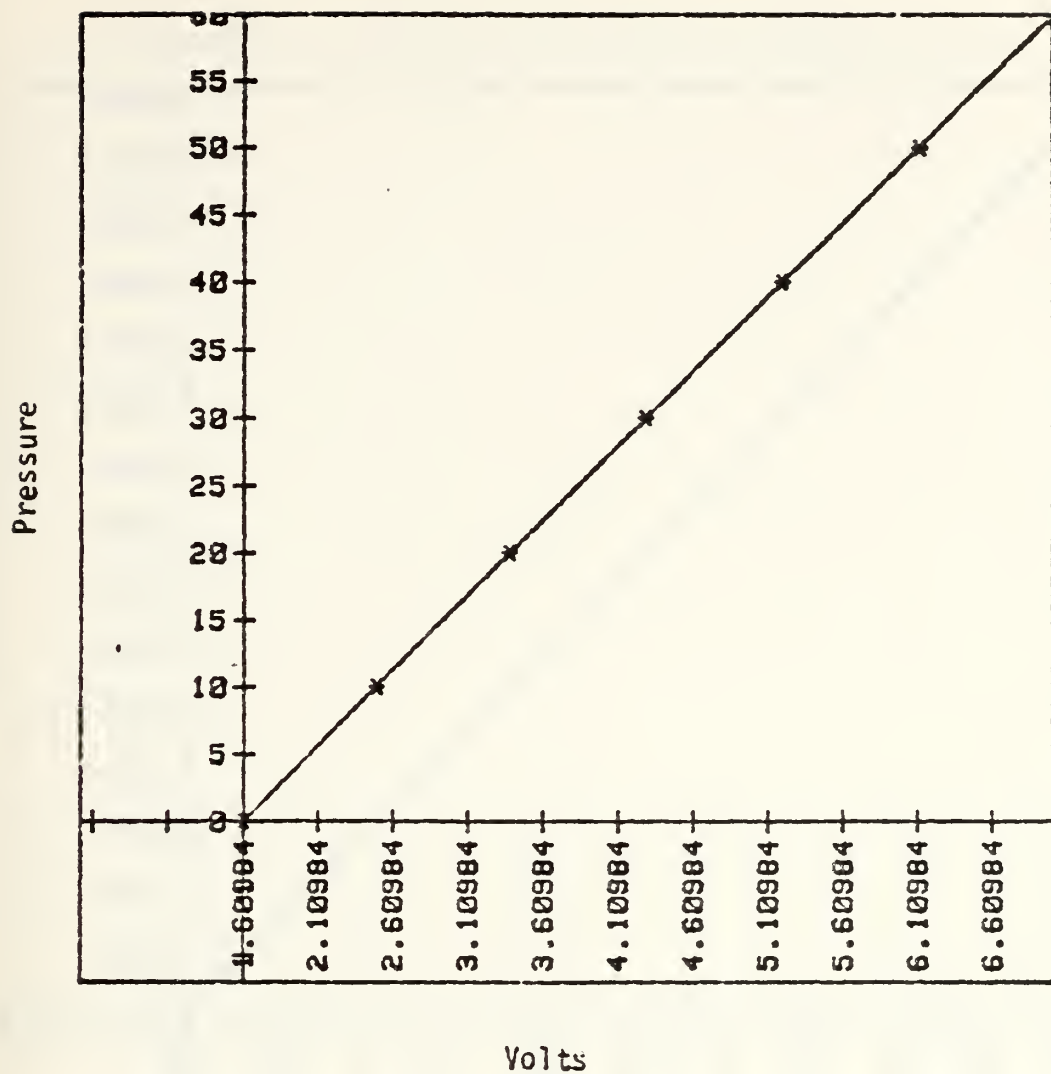
Calibration Plot of Pressure Transducer K



Calibration Plot of Pressure Transducer L

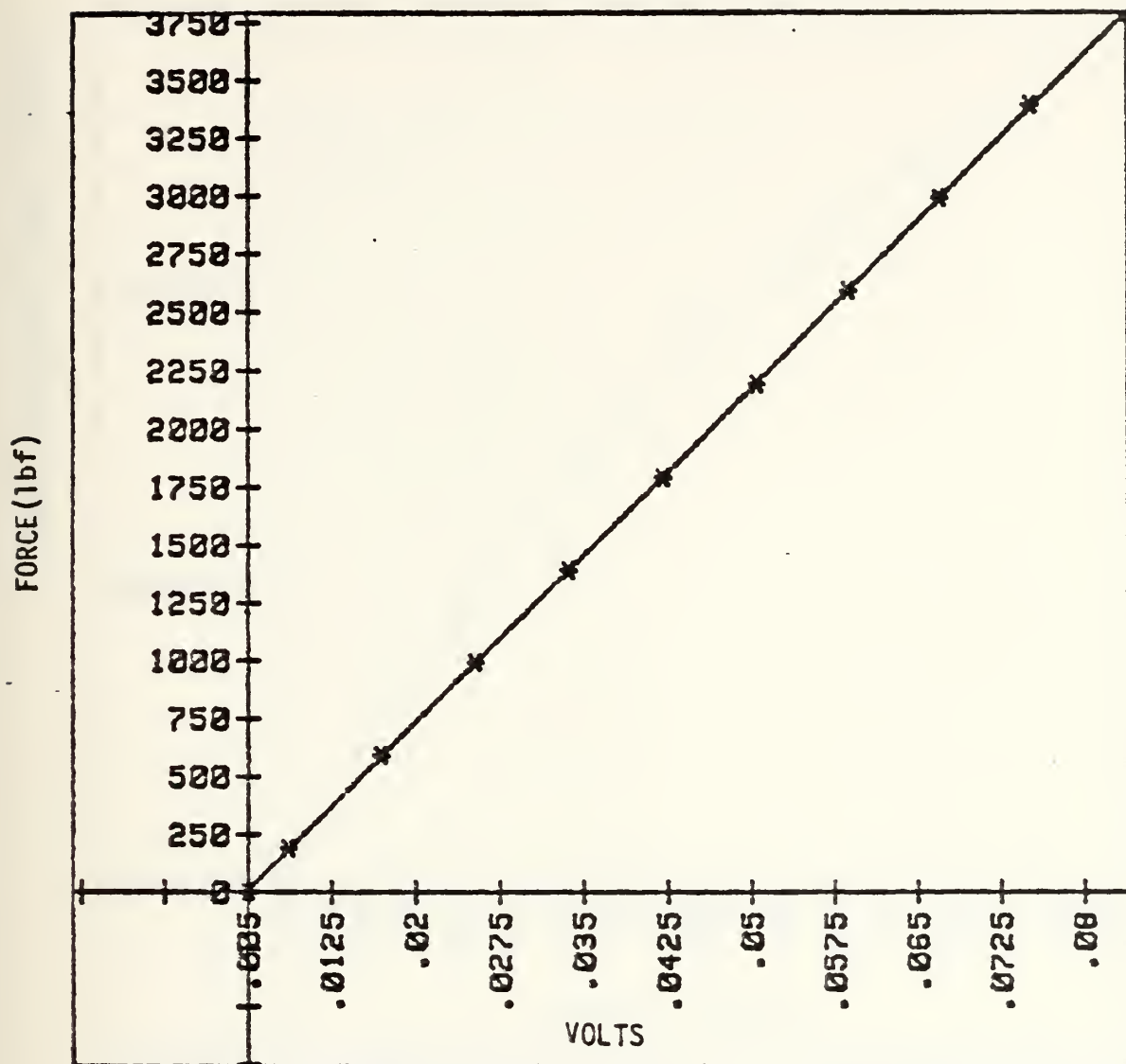


Calibration plot of pressure Transducer 0



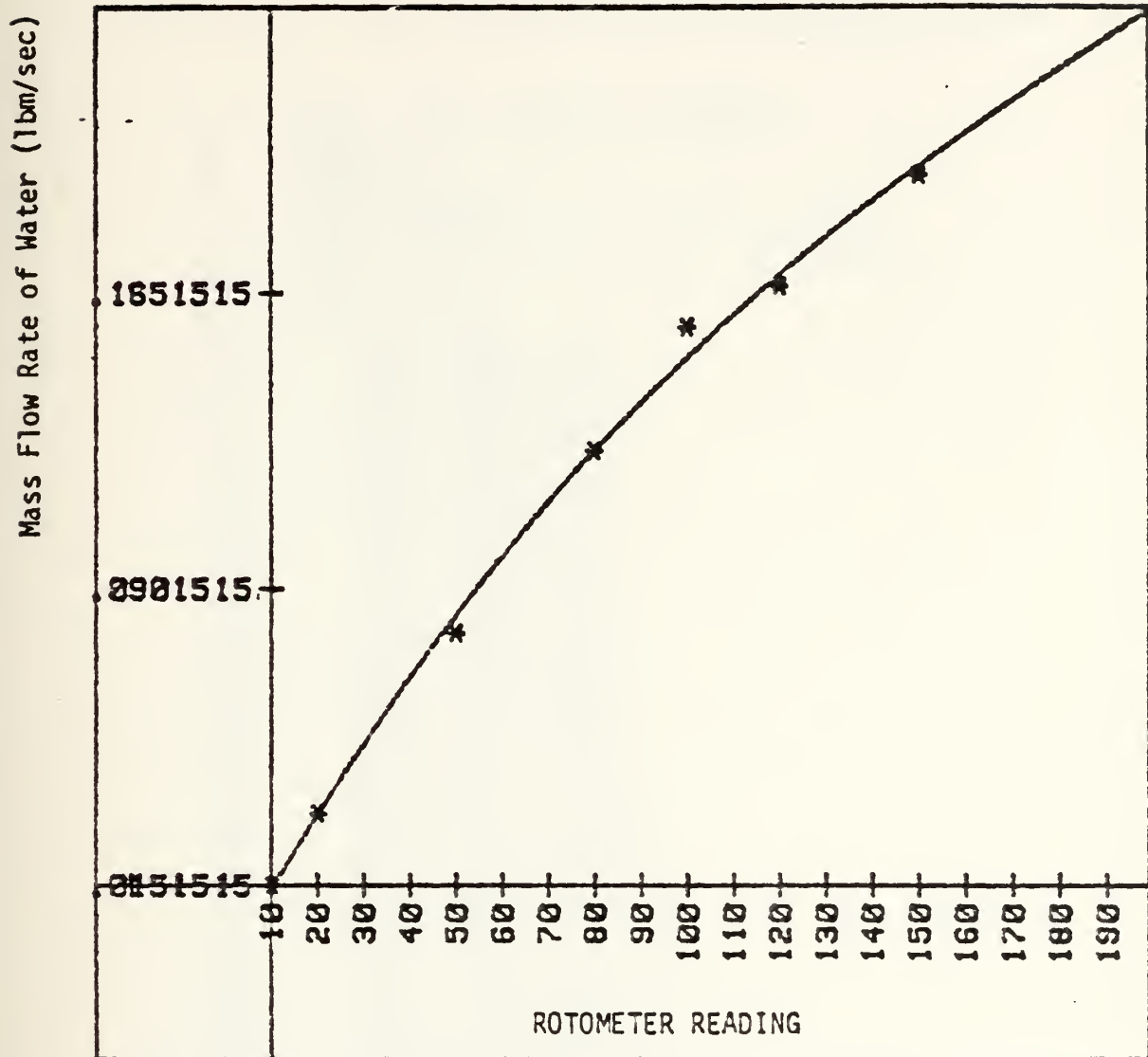
Calibration Plot of Pressure Transducer P

APPENDIX J: CALIBRATION PLOT FOR FORCE-BLOCK



Calibration Plot For Force-Block

APPENDIX K: CALIBRATION PLOT FOR ROTOMETER



Calibration Plot for Rotometer

APPENDIX L: DATA ACQUISITION AND ANALYSIS PROGRAM

```

3      PRINT "INPUT ROTOMETER READING"
4      INPUT Rr
5      PRINT Rr
7      DIM A(14),B(14),C(14),Dist(14),D(14)
8      DIM Press(14)
10     DIM X(18,100),Sum(18),Mean(18),Sum2(18)
30     N=10
40     FOR I=1 TO N
50         OUTPUT 709;"AI1VT1"
60         ENTER 709:X(1,I)
70         OUTPUT 709;"AI2VT1"
80         ENTER 709:X(2,I)
90         OUTPUT 709;"AI3VT1"
100        ENTER 709:X(3,I)
110       OUTPUT 709;"AI4VT1"
120       ENTER 709:X(4,I)
130       OUTPUT 709;"AI5VT1"
140       ENTER 709:X(5,I)
150       OUTPUT 709;"AI6VT1"
160       ENTER 709:X(6,I)
170       OUTPUT 709;"AI7VT1"
180       ENTER 709:X(7,I)
190       OUTPUT 709;"AI8VT1"
200       ENTER 709:X(8,I)
210       OUTPUT 709;"AI9VT1"
220       ENTER 709:X(9,I)
230       OUTPUT 709;"AI10VT1"
240       ENTER 709:X(10,I)
250       OUTPUT 709;"AI11VT1"
260       ENTER 709:X(11,I)
261      OUTPUT 709;"AI12VT1"
262      ENTER 709:X(12,I)
263      OUTPUT 709;"AI13VT1"
264      ENTER 709:X(13,I)
265      OUTPUT 709;"AI14VT1"
266      ENTER 709:X(14,I)
267      OUTPUT 709;"AI15VT1"
268      ENTER 709:X(15,I)
270     NEXT I
440     FOR J=1 TO 16
450         Sum(J)=0
460         FOR I=1 TO N
470             Sum(J)=Sum(J)+X(J,I)
480         NEXT I
490         Mean(J)=Sum(J)/N
510     NEXT J

```



```

520 FOR I=1 TO 14
530 READ A(I),B(I),C(I),D(I),Dist(I)
540 DATA -6.049177,3.92598,-.17336131,.0112105,.5
550 DATA -7.059265,4.233834,-.2292065,.01415403,1.5
560 DATA -6.4905288,3.93412037,-.160249802,.009448598,2.5
570 DATA -7.05653853,4.69207328,-.341175732,.0189756532,3.5
580 DATA -7.00950749,4.15163753,-.207173977,.0123697788,4.5
590 DATA -6.38855634,3.93348997,-.160546739,.0095126941,5.5
600 DATA -6.58938462,3.95696947,-.164270383,.0096133938,6.5
610 DATA -6.587731,3.90750953,-.158062598,.0094269372,7.5
620 DATA -6.59491204,3.94889685,-.162699726,.009565139,8.5
630 DATA -6.35328646,3.92659595,-.165085722,.0099773509,9.5
640 DATA -6.20324295,3.84628939,-.146968664,.0088046866,10.5
650 DATA -20.2065629,11.1571691,-.0859126,.004917379,0
660 DATA -20.6682414,11.0677155,-.07562378,.011185984,0
670 DATA -18.8267355,11.9281137,-.17715903,.011005888,0
680 Press(I)=A(I)+B(I)*Mean(I)+C(I)*Mean(I)^2+D(I)*Mean(I)^3
681 Press(I)=Press(I)+14.696
690 NEXT I

```



```

700 Fb=1/453.6*(-234.396482+48715.7753*Mean(15)-11261.538*Mean(15)^2+33899.3*M
ean(15)^3)
710 Mwater=-.0063268+.002097278*Rr-.00000658*Rr^2+.000000011*Rr^3
720 Fn=Fb*22.5/22.0
730 Dw=.920/12
740 Dd=3/12
750 E=1/(1-Dw/Dd)
760 Dp=Mean(14)-Mean(13)
770 Cc=.62
771 K=Cc*E
772 Aa=3.1416*Dw^2/4
774 Y=1-(.41+.35*(Dw/Dd)^4*(Dp/(1.4*Mean(14))))
780 Gc=32.2
790 Den=.076297*Mean(12)/14.696
800 Mair=K*Aa*Y*SQRT(2*Gc*Den*Dp*144)
810 Mtotal=Mair+Mwater
820 Vexit=Fn/(Mtotal)*32.2
830 PRINT "PRESSURE AS A FUNCTION OF DISTANCE"
840 PRINT " "
850 PRINT "DISTANCE(X)","PRESSURE"
860 PRINT " "
870 PRINT " "
880 FOR I=1 TO 14
890 PRINT Dist(I),Press(I)
900 NEXT I
910 PRINT "MASS FLOW RATE OF WATER" =";Mwater;"LBM/SEC"
920 PRINT "MASS FLOW RATE OF AIR" =";Mair;"LBM/SEC"
930 PRINT "TOTAL MASS FLOW RATE" =";Mtotal;"LBM/SEC"
940 PRINT "THRUST" =";Fn;"LBF"
950 PRINT "MIXTURE RATIO" =";Mwater/Mair"
960 PRINT "EXIT VELOCITY" =";Vexit;"FT/SEC"
970 PRINT "INLET PRESSURE" =";Press(12);"PSI"
980 END

```


INPUT ROTOMETER READING
0

PRESSURE AS A FUNCTION OF DISTANCE

DISTANCE (X)	PRESSURE
.5	14.5598137417
1.5	14.4607948757
2.5	14.4788575371
3.5	14.4188520649
4.5	14.4711792506
5.5	14.5553698274
6.5	14.4532490549
7.5	14.4461409662
8.5	14.5336111051
9.5	14.5262956477
10.5	14.5245848183
0	14.1098474897
0	11.8981971096
0	17.6235437008
MASS FLOW RATE OF WATER	= -.0063268 LBM/SEC
MASS FLOW RATE OF AIR	= .0110711550501 LBM/SEC
TOTAL MASS FLOW RATE	= .00474435505015 LBM/SEC
THRUST	= 1.76920486692 LBF
MIXTURE RATIO	= -.571467021403
EXIT VELOCITY	= 12007.6166544 FT/SEC
INLET PRESSURE	= 14.11098474897 PSI

APPENDIX M: DUAL-PHASE TWO-COMPONENT COMPUTER PROGRAM

```

$JOB
C*****
C REAL TWO-PHASE TWO-COMPONENT NOZZLE FLOW
C MODIFIED FOR USE AT NAVAL POSTGRADUATE SCHOOL
C PROF. J. SLADKY AND LT. T.C. MOLLIE
C*****
COMMON TZZZAY
DIMENSION TZZZAY(11200)
THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTOP
C IT MUST BE THE FIRST COMMON BLOCK
COMMON
1 ALPHS , ABAR , ALAM , ALPHAD , ALPHA , ALPHAB , ALPHMB ,
2 AB , BETAB , BETAMB , BETAS , BETA , BA ,
3 C , C1 , CAG1 , CAGMB , CAG , CALMB ,
4 CBG1 , CAL , CAG , CAGMB , CAG , CALMB ,
COMMON
6 CFOMS , CGMB , CGA , CGMS , CL1 , CL1B , CL1F ,
7 CL1S , CSAVE , D , D2 , D1A , DAF ,
8 D , DELIM , DELI , DELIS , DELIM , DELI , DELI2 ,
9 DELOS , DELSI , DELEO , DELTM , DELT , DELV2 ,
COMMON
1 DEMAGB , DEMAG , DEMBGB , DEMGB , DINT , DINT ,
2 DLSIS , DLSOS , DO , DP , DP , DP ,
3 DFI , DRO , DRI , DRI , DRI , DRI ,
4 DSAAX , DSAIN , DSAAY1 , DSAAY , DSAAY1 , DSAAY2 ,
5 DSRPS , DSX1 , DSX2 , DTG1 , DTG2 , DTG3 ,
COMMON
6 DTG , DTHI , DTHO , DTL1 , DTL2 , DTL3 ,
7 DT , DVBSQ , DVSQ , DVSQ , DVSQ , DVSQ ,
8 DYO , DZ , DZS , DZS , DZS , DZS ,
9 EMBG , EMBG , EMBG , EMBG , EMBG , EMBG ,
COMMON
1 EML , EMLS , EMT , ESO , EMBGP , EMBGP ,
2 H , HJ1 , HJ2 , HJ3 , HJ4 , HJ5 ,
3 HJ6 , HJ7 , HJ8 , HJ9 , HJ10 , HJ11 ,
4 HJ12 , HJ13 , HJ14 , HJ15 , HJ16 , HJ17 ,
COMMON
6 HJ18 , HJ19 , HJ20 , HJ21 , HJ22 , HJ23 ,
7 HJ24 , HJ25 , HJ26 , HJ27 , HJ28 , HJ29 ,
8 HJ30 , HJ31 , HJ32 , HJ33 , HJ34 , HJ35 ,
9 HJ36 , HJ37 , HJ38 , HJ39 , HJ40 , HJ41 ,
COMMON
1 HJ42 , HJ43 , HJ44 , HJ45 , HJ46 , HJ47 ,
2 HJ48 , HJ49 , HJ50 , HJ51 , HJ52 , HJ53 ,
3 HJ54 , HJ55 , HJ56 , HJ57 , HJ58 , HJ59 ,
4 HJ60 , HJ61 , HJ62 , HJ63 , HJ64 , HJ65 ,
COMMON
6 HJ66 , HJ67 , HJ68 , HJ69 , HJ70 , HJ71 ,
7 HJ72 , HJ73 , HJ74 , HJ75 , HJ76 , HJ77 ,
8 HJ78 , HJ79 , HJ80 , HJ81 , HJ82 , HJ83 ,
9 HJ84 , HJ85 , HJ86 , HJ87 , HJ88 , HJ89 ,
COMMON
1 HJ90 , HJ91 , HJ92 , HJ93 , HJ94 , HJ95 ,
2 HJ96 , HJ97 , HJ98 , HJ99 , HJ100 , HJ101 ,
3 HJ102 , HJ103 , HJ104 , HJ105 , HJ106 , HJ107 ,
4 HJ108 , HJ109 , HJ110 , HJ111 , HJ112 , HJ113 ,
COMMON
6 HJ114 , HJ115 , HJ116 , HJ117 , HJ118 , HJ119 ,
7 HJ120 , HJ121 , HJ122 , HJ123 , HJ124 , HJ125 ,
8 HJ126 , HJ127 , HJ128 , HJ129 , HJ130 , HJ131 ,
9 HJ132 , HJ133 , HJ134 , HJ135 , HJ136 , HJ137 ,
COMMON
1 HJ138 , HJ139 , HJ140 , HJ141 , HJ142 , HJ143 ,
2 HJ144 , HJ145 , HJ146 , HJ147 , HJ148 , HJ149 ,
3 HJ150 , HJ151 , HJ152 , HJ153 , HJ154 , HJ155 ,
4 HJ156 , HJ157 , HJ158 , HJ159 , HJ160 , HJ161 ,
COMMON
6 HJ162 , HJ163 , HJ164 , HJ165 , HJ166 , HJ167 ,
7 HJ168 , HJ169 , HJ170 , HJ171 , HJ172 , HJ173 ,
8 HJ174 , HJ175 , HJ176 , HJ177 , HJ178 , HJ179 ,
9 HJ180 , HJ181 , HJ182 , HJ183 , HJ184 , HJ185 ,
COMMON
1 HJ186 , HJ187 , HJ188 , HJ189 , HJ190 , HJ191 ,
2 HJ192 , HJ193 , HJ194 , HJ195 , HJ196 , HJ197 ,
3 HJ198 , HJ199 , HJ200 , HJ201 , HJ202 , HJ203 ,
4 HJ204 , HJ205 , HJ206 , HJ207 , HJ208 , HJ209 ,
COMMON
6 HJ210 , HJ211 , HJ212 , HJ213 , HJ214 , HJ215 ,
7 HJ216 , HJ217 , HJ218 , HJ219 , HJ220 , HJ221 ,
8 HJ222 , HJ223 , HJ224 , HJ225 , HJ226 , HJ227 ,
9 HJ228 , HJ229 , HJ230 , HJ231 , HJ232 , HJ233 ,
COMMON
1 HJ234 , HJ235 , HJ236 , HJ237 , HJ238 , HJ239 ,
2 HJ240 , HJ241 , HJ242 , HJ243 , HJ244 , HJ245 ,
3 HJ246 , HJ247 , HJ248 , HJ249 , HJ250 , HJ251 ,
4 HJ252 , HJ253 , HJ254 , HJ255 , HJ256 , HJ257 ,
COMMON
6 HJ258 , HJ259 , HJ260 , HJ261 , HJ262 , HJ263 ,
7 HJ264 , HJ265 , HJ266 , HJ267 , HJ268 , HJ269 ,
8 HJ270 , HJ271 , HJ272 , HJ273 , HJ274 , HJ275 ,
9 HJ276 , HJ277 , HJ278 , HJ279 , HJ280 , HJ281 ,
COMMON
1 HJ282 , HJ283 , HJ284 , HJ285 , HJ286 , HJ287 ,
2 HJ288 , HJ289 , HJ290 , HJ291 , HJ292 , HJ293 ,
3 HJ294 , HJ295 , HJ296 , HJ297 , HJ298 , HJ299 ,
4 HJ300 , HJ301 , HJ302 , HJ303 , HJ304 , HJ305 ,
COMMON
6 HJ306 , HJ307 , HJ308 , HJ309 , HJ310 , HJ311 ,
7 HJ312 , HJ313 , HJ314 , HJ315 , HJ316 , HJ317 ,
8 HJ318 , HJ319 , HJ320 , HJ321 , HJ322 , HJ323 ,
9 HJ324 , HJ325 , HJ326 , HJ327 , HJ328 , HJ329 ,
COMMON
1 HJ330 , HJ331 , HJ332 , HJ333 , HJ334 , HJ335 ,
2 HJ336 , HJ337 , HJ338 , HJ339 , HJ340 , HJ341 ,
3 HJ342 , HJ343 , HJ344 , HJ345 , HJ346 , HJ347 ,
4 HJ348 , HJ349 , HJ350 , HJ351 , HJ352 , HJ353 ,
COMMON
6 HJ354 , HJ355 , HJ356 , HJ357 , HJ358 , HJ359 ,
7 HJ360 , HJ361 , HJ362 , HJ363 , HJ364 , HJ365 ,
8 HJ366 , HJ367 , HJ368 , HJ369 , HJ370 , HJ371 ,
9 HJ372 , HJ373 , HJ374 , HJ375 , HJ376 , HJ377 ,
COMMON
1 HJ378 , HJ379 , HJ380 , HJ381 , HJ382 , HJ383 ,
2 HJ384 , HJ385 , HJ386 , HJ387 , HJ388 , HJ389 ,
3 HJ390 , HJ391 , HJ392 , HJ393 , HJ394 , HJ395 ,
4 HJ396 , HJ397 , HJ398 , HJ399 , HJ400 , HJ401 ,
COMMON
6 HJ402 , HJ403 , HJ404 , HJ405 , HJ406 , HJ407 ,
7 HJ408 , HJ409 , HJ410 , HJ411 , HJ412 , HJ413 ,
8 HJ414 , HJ415 , HJ416 , HJ417 , HJ418 , HJ419 ,
9 HJ420 , HJ421 , HJ422 , HJ423 , HJ424 , HJ425 ,
COMMON
1 HJ426 , HJ427 , HJ428 , HJ429 , HJ430 , HJ431 ,
2 HJ432 , HJ433 , HJ434 , HJ435 , HJ436 , HJ437 ,
3 HJ438 , HJ439 , HJ440 , HJ441 , HJ442 , HJ443 ,
4 HJ444 , HJ445 , HJ446 , HJ447 , HJ448 , HJ449 ,
COMMON
6 HJ450 , HJ451 , HJ452 , HJ453 , HJ454 , HJ455 ,
7 HJ456 , HJ457 , HJ458 , HJ459 , HJ460 , HJ461 ,
8 HJ462 , HJ463 , HJ464 , HJ465 , HJ466 , HJ467 ,
9 HJ468 , HJ469 , HJ470 , HJ471 , HJ472 , HJ473 ,
COMMON
1 HJ474 , HJ475 , HJ476 , HJ477 , HJ478 , HJ479 ,
2 HJ480 , HJ481 , HJ482 , HJ483 , HJ484 , HJ485 ,
3 HJ486 , HJ487 , HJ488 , HJ489 , HJ490 , HJ491 ,
4 HJ492 , HJ493 , HJ494 , HJ495 , HJ496 , HJ497 ,
COMMON
6 HJ498 , HJ499 , HJ500 , HJ501 , HJ502 , HJ503 ,
7 HJ504 , HJ505 , HJ506 , HJ507 , HJ508 , HJ509 ,
8 HJ510 , HJ511 , HJ512 , HJ513 , HJ514 , HJ515 ,
9 HJ516 , HJ517 , HJ518 , HJ519 , HJ520 , HJ521 ,
COMMON
1 HJ522 , HJ523 , HJ524 , HJ525 , HJ526 , HJ527 ,
2 HJ528 , HJ529 , HJ530 , HJ531 , HJ532 , HJ533 ,
3 HJ534 , HJ535 , HJ536 , HJ537 , HJ538 , HJ539 ,
4 HJ540 , HJ541 , HJ542 , HJ543 , HJ544 , HJ545 ,
COMMON
6 HJ546 , HJ547 , HJ548 , HJ549 , HJ550 , HJ551 ,
7 HJ552 , HJ553 , HJ554 , HJ555 , HJ556 , HJ557 ,
8 HJ558 , HJ559 , HJ560 , HJ561 , HJ562 , HJ563 ,
9 HJ564 , HJ565 , HJ566 , HJ567 , HJ568 , HJ569 ,
COMMON
1 HJ570 , HJ571 , HJ572 , HJ573 , HJ574 , HJ575 ,
2 HJ576 , HJ577 , HJ578 , HJ579 , HJ580 , HJ581 ,
3 HJ582 , HJ583 , HJ584 , HJ585 , HJ586 , HJ587 ,
4 HJ588 , HJ589 , HJ590 , HJ591 , HJ592 , HJ593 ,
COMMON
6 HJ594 , HJ595 , HJ596 , HJ597 , HJ598 , HJ599 ,
7 HJ600 , HJ601 , HJ602 , HJ603 , HJ604 , HJ605 ,
8 HJ606 , HJ607 , HJ608 , HJ609 , HJ610 , HJ611 ,
9 HJ612 , HJ613 , HJ614 , HJ615 , HJ616 , HJ617 ,
COMMON
1 HJ618 , HJ619 , HJ620 , HJ621 , HJ622 , HJ623 ,
2 HJ624 , HJ625 , HJ626 , HJ627 , HJ628 , HJ629 ,
3 HJ630 , HJ631 , HJ632 , HJ633 , HJ634 , HJ635 ,
4 HJ636 , HJ637 , HJ638 , HJ639 , HJ640 , HJ641 ,
COMMON
6 HJ642 , HJ643 , HJ644 , HJ645 , HJ646 , HJ647 ,
7 HJ648 , HJ649 , HJ650 , HJ651 , HJ652 , HJ653 ,
8 HJ654 , HJ655 , HJ656 , HJ657 , HJ658 , HJ659 ,
9 HJ660 , HJ661 , HJ662 , HJ663 , HJ664 , HJ665 ,
COMMON
1 HJ666 , HJ667 , HJ668 , HJ669 , HJ670 , HJ671 ,
2 HJ672 , HJ673 , HJ674 , HJ675 , HJ676 , HJ677 ,
3 HJ678 , HJ679 , HJ680 , HJ681 , HJ682 , HJ683 ,
4 HJ684 , HJ685 , HJ686 , HJ687 , HJ688 , HJ689 ,
COMMON
6 HJ690 , HJ691 , HJ692 , HJ693 , HJ694 , HJ695 ,
7 HJ696 , HJ697 , HJ698 , HJ699 , HJ700 , HJ701 ,
8 HJ702 , HJ703 , HJ704 , HJ705 , HJ706 , HJ707 ,
9 HJ708 , HJ709 , HJ710 , HJ711 , HJ712 , HJ713 ,
COMMON
1 HJ714 , HJ715 , HJ716 , HJ717 , HJ718 , HJ719 ,
2 HJ720 , HJ721 , HJ722 , HJ723 , HJ724 , HJ725 ,
3 HJ726 , HJ727 , HJ728 , HJ729 , HJ730 , HJ731 ,
4 HJ732 , HJ733 , HJ734 , HJ735 , HJ736 , HJ737 ,
COMMON
6 HJ738 , HJ739 , HJ740 , HJ741 , HJ742 , HJ743 ,
7 HJ744 , HJ745 , HJ746 , HJ747 , HJ748 , HJ749 ,
8 HJ750 , HJ751 , HJ752 , HJ753 , HJ754 , HJ755 ,
9 HJ756 , HJ757 , HJ758 , HJ759 , HJ760 , HJ761 ,
COMMON
1 HJ762 , HJ763 , HJ764 , HJ765 , HJ766 , HJ767 ,
2 HJ768 , HJ769 , HJ770 , HJ771 , HJ772 , HJ773 ,
3 HJ774 , HJ775 , HJ776 , HJ777 , HJ778 , HJ779 ,
4 HJ780 , HJ781 , HJ782 , HJ783 , HJ784 , HJ785 ,
COMMON
6 HJ786 , HJ787 , HJ788 , HJ789 , HJ790 , HJ791 ,
7 HJ792 , HJ793 , HJ794 , HJ795 , HJ796 , HJ797 ,
8 HJ798 , HJ799 , HJ800 , HJ801 , HJ802 , HJ803 ,
9 HJ804 , HJ805 , HJ806 , HJ807 , HJ808 , HJ809 ,
COMMON
1 HJ810 , HJ811 , HJ812 , HJ813 , HJ814 , HJ815 ,
2 HJ816 , HJ817 , HJ818 , HJ819 , HJ820 , HJ821 ,
3 HJ822 , HJ823 , HJ824 , HJ825 , HJ826 , HJ827 ,
4 HJ828 , HJ829 , HJ830 , HJ831 , HJ832 , HJ833 ,
COMMON
6 HJ834 , HJ835 , HJ836 , HJ837 , HJ838 , HJ839 ,
7 HJ840 , HJ841 , HJ842 , HJ843 , HJ844 , HJ845 ,
8 HJ846 , HJ847 , HJ848 , HJ849 , HJ850 , HJ851 ,
9 HJ852 , HJ853 , HJ854 , HJ855 , HJ856 , HJ857 ,
COMMON
1 HJ858 , HJ859 , HJ860 , HJ861 , HJ862 , HJ863 ,
2 HJ864 , HJ865 , HJ866 , HJ867 , HJ868 , HJ869 ,
3 HJ870 , HJ871 , HJ872 , HJ873 , HJ874 , HJ875 ,
4 HJ876 , HJ877 , HJ878 , HJ879 , HJ880 , HJ881 ,
COMMON
6 HJ882 , HJ883 , HJ884 , HJ885 , HJ886 , HJ887 ,
7 HJ888 , HJ889 , HJ890 , HJ891 , HJ892 , HJ893 ,
8 HJ894 , HJ895 , HJ896 , HJ897 , HJ898 , HJ899 ,
9 HJ900 , HJ901 , HJ902 , HJ903 , HJ904 , HJ905 ,
COMMON
1 HJ906 , HJ907 , HJ908 , HJ909 , HJ910 , HJ911 ,
2 HJ912 , HJ913 , HJ914 , HJ915 , HJ916 , HJ917 ,
3 HJ918 , HJ919 , HJ920 , HJ921 , HJ922 , HJ923 ,
4 HJ924 , HJ925 , HJ926 , HJ927 , HJ928 , HJ929 ,
COMMON
6 HJ930 , HJ931 , HJ932 , HJ933 , HJ934 , HJ935 ,
7 HJ936 , HJ937 , HJ938 , HJ939 , HJ940 , HJ941 ,
8 HJ942 , HJ943 , HJ944 , HJ945 , HJ946 , HJ947 ,
9 HJ948 , HJ949 , HJ950 , HJ951 , HJ952 , HJ953 ,
COMMON
1 HJ954 , HJ955 , HJ956 , HJ957 , HJ958 , HJ959 ,
2 HJ960 , HJ961 , HJ962 , HJ963 , HJ964 , HJ965 ,
3 HJ966 , HJ967 , HJ968 , HJ969 , HJ970 , HJ971 ,
4 HJ972 , HJ973 , HJ974 , HJ975 , HJ976 , HJ977 ,
COMMON
6 HJ978 , HJ979 , HJ980 , HJ981 , HJ982 , HJ983 ,
7 HJ984 , HJ985 , HJ986 , HJ987 , HJ988 , HJ989 ,
8 HJ990 , HJ991 , HJ992 , HJ993 , HJ994 , HJ995 ,
9 HJ996 , HJ997 , HJ998 , HJ999 , HJ1000 , HJ1001 ,
COMMON
1 HJ1002 , HJ1003 , HJ1004 , HJ1005 , HJ1006 , HJ1007 ,
2 HJ1008 , HJ1009 , HJ1010 , HJ1011 , HJ1012 , HJ1013 ,
3 HJ1014 , HJ1015 , HJ1016 , HJ1017 , HJ1018 , HJ1019 ,
4 HJ1020 , HJ1021 , HJ1022 , HJ1023 , HJ1024 , HJ1025 ,
COMMON
6 HJ1026 , HJ1027 , HJ1028 , HJ1029 , HJ1030 , HJ1031 ,
7 HJ1032 , HJ1033 , HJ1034 , HJ1035 , HJ1036 , HJ1037 ,
8 HJ1038 , HJ1039 , HJ1040 , HJ1041 , HJ1042 , HJ1043 ,
9 HJ1044 , HJ1045 , HJ1046 , HJ1047 , HJ1048 , HJ1049 ,
COMMON
1 HJ1050 , HJ1051 , HJ1052 , HJ1053 , HJ1054 , HJ1055 ,
2 HJ1056 , HJ1057 , HJ1058 , HJ1059 , HJ1060 , HJ1061 ,
3 HJ1062 , HJ1063 , HJ1064 , HJ1065 , HJ1066 , HJ1067 ,
4 HJ1068 , HJ1069 , HJ1070 , HJ1071 , HJ1072 , HJ1073 ,
COMMON
6 HJ1074 , HJ1075 , HJ1076 , HJ1077 , HJ1078 , HJ1079 ,
7 HJ1080 , HJ1081 , HJ1082 , HJ1083 , HJ1084 , HJ1085 ,
8 HJ1086 , HJ1087 , HJ1088 , HJ1089 , HJ1090 , HJ1091 ,
9 HJ1092 , HJ1093 , HJ1094 , HJ1095 , HJ1096 , HJ1097 ,
COMMON
1 HJ1098 , HJ1099 , HJ1100 , HJ1101 , HJ1102 , HJ1103 ,
2 HJ1104 , HJ1105 , HJ1106 , HJ1107 , HJ1108 , HJ1109 ,
3 HJ1110 , HJ1111 , HJ1112 , HJ1113 , HJ1114 , HJ1115 ,
4 HJ1116 , HJ1117 , HJ1118 , HJ1119 , HJ1120 , HJ1121 ,
COMMON
6 HJ1122 , HJ1123 , HJ1124 , HJ1125 , HJ1126 , HJ1127 ,
7 HJ1128 , HJ1129 , HJ1130 , HJ1131 , HJ1132 , HJ1133 ,
8 HJ1134 , HJ1135 , HJ1136 , HJ1137 , HJ1138 , HJ1139 ,
9 HJ1140 , HJ1141 , HJ1142 , HJ1143 , HJ1144 , HJ1145 ,
COMMON
1 HJ1146 , HJ1147 , HJ1148 , HJ1149 , HJ1150 , HJ1151 ,
2 HJ1152 , HJ1153 , HJ1154 , HJ1155 , HJ1156 , HJ1157 ,
3 HJ1158 , HJ1159 , HJ1160 , HJ1161 , HJ1162 , HJ1163 ,
4 HJ1164 , HJ1165 , HJ1166 , HJ1167 , HJ1168 , HJ1169 ,
COMMON
6 HJ1170 , HJ1171 , HJ1172 , HJ1173 , HJ1174 , HJ1175 ,
7 HJ1176 , HJ1177 , HJ1178 , HJ1179 , HJ1180 , HJ1181 ,
8 HJ1182 , HJ1183 , HJ1184 , HJ1185 , HJ1186 , HJ1187 ,
9 HJ1188 , HJ1189 , HJ1190 , HJ1191 , HJ1192 , HJ1193 ,
COMMON
1 HJ1194 , HJ1195 , HJ1196 , HJ1197 , HJ1198 , HJ1199 ,
2 HJ1200 , HJ1201 , HJ1202 , HJ1203 , HJ1204 , HJ1205 ,
3 HJ1206 , HJ1207 , HJ1208 , HJ1209 , HJ1210 , HJ1211 ,
4 HJ1212 , HJ1213 , HJ1214 , HJ1215 , HJ1216 , HJ1217 ,
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7 HJ1224 , HJ1225 , HJ1226 , HJ1227 , HJ1228 , HJ1229 ,
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9 HJ1236 , HJ1237 , HJ1238 , HJ1239 , HJ1240 , HJ1241 ,
COMMON
1 HJ1242 , HJ1243 , HJ1244 , HJ1245 , HJ1246 , HJ1247 ,
2 HJ1248 , HJ1249 , HJ1250 , HJ1251 , HJ1252 , HJ1253 ,
3 HJ1254 , HJ1255 , HJ1256 , HJ1257 , HJ1258 , HJ1259 ,
4 HJ1260 , HJ1261 , HJ1262 , HJ1263 , HJ1264 , HJ1265 ,
COMMON
6 HJ1266 , HJ1267 , HJ1268 , HJ1269 , HJ1270 , HJ1271 ,
7 HJ1272 , HJ1273 , HJ1274 , HJ1275 , HJ1276 , HJ1277 ,
8 HJ1278 , HJ1279 , HJ1280 , HJ1281 , HJ1282 , HJ1283 ,
9 HJ1284 , HJ1285 , HJ1286 , HJ1287 , HJ1288 , HJ1289 ,
COMMON
1 HJ1290 , HJ1291 , HJ1292 , HJ1293 , HJ1294 , HJ1295 ,
2 HJ1296 , HJ1297 , HJ1298 , HJ1299 , HJ1300 , HJ1301 ,
3 HJ1302 , HJ1303 , HJ1304 , HJ1305 , HJ1306 , HJ1307 ,
4 HJ1308 , HJ1309 , HJ1310 , HJ1311 , HJ1312 , HJ1313 ,
COMMON
6 HJ1314 , HJ1315 , HJ1316 , HJ1317 , HJ1318 , HJ1319 ,
7 HJ1320 , HJ1321 , HJ1322 , HJ1323 , HJ1324 , HJ1325 ,
8 HJ1326 , HJ1327 , HJ1328 , HJ1329 , HJ1330 , HJ1331 ,
9 HJ1332 , HJ1333 , HJ1334 , HJ1335 , HJ1336 , HJ1337 ,
COMMON
1 HJ1338 , HJ1339 , HJ1340 , HJ1341 , HJ1342 , HJ1343 ,
2 HJ1344 , HJ1345 , HJ1346 , HJ1347 , HJ1348 , HJ1349 ,
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4 HJ1356 , HJ1357 , HJ1358 , HJ1359 , HJ1360 , HJ1361 ,
COMMON
6 HJ1362 , HJ1363 , HJ1364 , HJ1365 , HJ1366 , HJ1367 ,
7 HJ1368 , HJ1369 , HJ1370 , HJ1371 , HJ1372 , HJ1373 ,
8 HJ1374 , HJ1375 , HJ1376 , HJ1377 , HJ1378 , HJ1379 ,
9 HJ1380 , HJ1381 , HJ1382 , HJ1383 , HJ1384 , HJ1385 ,
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2 HJ1392 , HJ1393 , HJ1394 , HJ1395 , HJ1396 , HJ1397 ,
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4 HJ1404 , HJ1405 , HJ1406 , HJ1407 , HJ1408 , HJ1409 ,
COMMON
6 HJ1410 , HJ1411 , HJ1412 , HJ1413 , HJ1414 , HJ1415 ,
7 HJ1416 , HJ1417 , HJ1418 , HJ1419 , HJ1420 , HJ1421 ,
8 HJ1422 , HJ1423 , HJ1424 , HJ1425 , HJ1426 , HJ1427 ,
9 HJ1428 , HJ1429 , HJ1430 , HJ1431 , HJ1432 , HJ1433 ,
COMMON
1 HJ1434 , HJ1435 , HJ1436 , HJ1437 , HJ1438 , HJ1439 ,
2 HJ1440 , HJ1441 , HJ1442 , HJ1443 , HJ1444 , HJ1445 ,
3 HJ1446 , HJ1447 , HJ1448 , HJ1449 , HJ1450 , HJ1451 ,
4 HJ1452 , HJ1453 , HJ1454 , HJ1455 , HJ1456 , HJ1457 ,
COMMON
6 HJ1458 , HJ1459 , HJ1460 , HJ1461 , HJ1462 , HJ1463 ,
7 HJ1464 , HJ1465 , HJ1466 , HJ1467 , HJ1468 , HJ1469 ,
8 HJ1470 , HJ1471 , HJ1472 , HJ1473 , HJ1474 , HJ1475 ,
9 HJ1476 , HJ1477 , HJ1478 , HJ1479 , HJ1480 , HJ1481 ,
COMMON
1 HJ1482 , HJ1483 , HJ1484 , HJ1485 , HJ1486 , HJ1487 ,
2 HJ1488 , HJ1489 , HJ1490 , HJ1491 , HJ1492 , HJ1493 ,
3 HJ1494 , HJ1495 , HJ1496 , HJ1497 , HJ1498 , HJ1499 ,
4 HJ1500 , HJ1501 , HJ1502 , HJ1503 , HJ1504 , HJ1505 ,
COMMON
6 HJ1506 , HJ1507 , HJ1508 , HJ1509 , HJ1510 , HJ1511 ,
7 HJ1512 , HJ1513 , HJ1514 , HJ1515 , HJ1516 , HJ1517 ,
8 HJ1518 , HJ1519 , HJ1520 , HJ1521 , HJ1522 , HJ1523 ,
9 HJ1524 , HJ1525 , HJ1526 , HJ1527 , HJ1528 , HJ1529 ,
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1 HJ1530 , HJ1531 , HJ1532 , HJ1533 , HJ1534 , HJ1535 ,
2 HJ1536 , HJ1537 , HJ1538 , HJ1539 , HJ1540 , HJ1541 ,
3 HJ1542 , HJ1543 , HJ1544 , HJ1545 , HJ1546 , HJ1547 ,
4 HJ1548 , HJ1549 , HJ1550 , HJ1551 , HJ1552 , HJ1553 ,
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6 HJ1554 , HJ1555 , HJ1556 , HJ1557 , HJ1558 , HJ1559 ,
7 HJ1560 , HJ1561 , HJ1562 , HJ1563 , HJ1564 , HJ1565 ,
8 HJ1566 , HJ1567 , HJ1568 , HJ1569 , HJ1570 , HJ1571 ,
9 HJ1572 , HJ1573 , HJ1574 , HJ1575 , HJ1576 , HJ1577 ,
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1 HJ1578 , HJ1579 , HJ1580 , HJ1581 , HJ1582 , HJ1583 ,
2 HJ1584 , HJ1585 , HJ1586 , HJ1587 , HJ1588 , HJ1589 ,
3 HJ1590 , HJ1591 , HJ1592 , HJ1593 , HJ1594 , HJ1595 ,
4 HJ1596 , HJ1597 , HJ1598 , HJ1599 , HJ1600 , HJ1601 ,
COMMON
6 HJ1602 , HJ1603 , HJ1604 , HJ1605 , HJ1606 , HJ1607 ,
7 HJ1608 , HJ1609 , HJ1610 , HJ1611 , HJ1612 , HJ1613 ,
8 HJ1614 , HJ1615 , HJ1616 , HJ1617 , HJ1618 , HJ1619 ,
9 HJ1620 , HJ1621 , HJ1622 , HJ1623 , HJ1624 , HJ1625 ,
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1 HJ1626 , HJ1627 , HJ1628 , HJ1629 , HJ1630 , HJ1631 ,
2 HJ1632 , HJ1633 , HJ1634 , HJ1635 , HJ1636 , HJ1637 ,
3 HJ1638 , HJ1639 , HJ1640 , HJ1641 , HJ1642 , HJ1643 ,
4 HJ1644 , HJ1645 , HJ1646 , HJ1647 , HJ1648 , HJ1649 ,
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6 HJ1650 , HJ1651 , HJ1652 , HJ1653 , HJ1654 , HJ1655 ,
7 HJ1656 , HJ1657 , HJ1658 , HJ1659 , HJ1660 , HJ1661 ,
8 HJ1662 , HJ1663 , HJ1664 , HJ1665 , HJ1666 , HJ1667 ,
9 HJ1668 , HJ1669 , HJ1670 , HJ1671 , HJ1672 , HJ1673 ,
COMMON
1 HJ1674 , HJ1675 , HJ1676 , HJ1677 , HJ1678 , HJ1679 ,
2 HJ1680 , HJ1681 , HJ1682 , HJ1683 , HJ1684 , HJ1685 ,
3 HJ1686 , HJ1687 , HJ1688 , HJ1689 , HJ1690 , HJ1691 ,
4 HJ1692 , HJ1693 , HJ1694 , HJ1695 , HJ1696 , HJ1697 ,
COMMON
6 HJ1698 , HJ1699 , HJ1700 , HJ1701 , HJ1702 , HJ1703 ,
7 HJ1704 , HJ1705 , HJ1706 , HJ1707 , HJ1708 , HJ1709 ,
8 HJ1710 , HJ1711 , HJ1712 , HJ1713 , HJ1714 , HJ1715 ,
9 HJ1716 , HJ1717 , HJ1718 , HJ1719 , HJ1720 , HJ1721 ,
COMMON
1 HJ1722 , HJ1723 , HJ1724 , HJ1725 , HJ1726 , HJ1727 ,
2 HJ1728 , HJ1729 , HJ1730 , HJ1731 , HJ1732 , HJ1733 ,
3 HJ1734 , HJ1735 , HJ1736 , HJ1737
```


2	DIMENSION PL(10), YO, YOS, ZZZ, NSTMT	MAIN 0860
	DIMENSION NDRAW(75)	MAIN 0870
	DIMENSION DATE(5), CASE(3), OID(8), AP(2,75), PL1(10),	MAIN 0880
1	C(6), AP(2,75), XXA(4), DSRAY(100), DSRAY1(100), TBAY(100), TBAY1(100)	MAIN 0890
21	(100), DRAY(75), HT(18), DINT(8)	MAIN 0900
	EQUIVALENCE (NDRAW(1), DRAY(1))	MAIN 0910
	XX=-1.0	MAIN 0920
	SMIN=1.0E-6	MAIN 0930
	ISERO=0	MAIN 0940
	ISER=75	MAIN 0950
	DINT(1)=.5	MAIN 0960
	DINT(2)=.1	MAIN 0970
	DINT(3)=.01	MAIN 0980
	DINT(4)=.001	MAIN 0990
	DINT(5)=.0001	MAIN 1000
	DINT(6)=.00001	MAIN 1010
	DINT(7)=.000001	MAIN 1020
	DINT(8)=.0000001	MAIN 1030
	CALL ADATA	MAIN 1040
C	INITIALIZE TABLE TAPP, BRING IN PERMANENT TABLES (ONE-DIMENSIONAL),	MAIN 1230
C	FILL ARRAY INDICATING TEMPERATURES INCLUDED IN TWO	MAIN 1240
C	DIMENSIONAL TABLES, INITIALIZE PAGE COUNT.	MAIN 1250
	5 LPGET=1	MAIN 1260
	CALL TABLE	MAIN 1270
	CALL INITER (VAR,0,T,P)	MAIN 1280
C	ACTIVATE THE FOLLOWING CARD TO GET A PRINTOUT OF THE PROPERTIES	MAIN 1290
	CALL INITER (VAR,20,T,P)	MAIN 1300
	NSTMT=999	MAIN 1310
100	CONTINUE	MAIN 1320
	CALL SECT1	MAIN 1330
	IF (NSTMT-5) 999,5,101	MAIN 1340
101	CONTINUE	MAIN 1350
	IF (NSTMT-99) 999,99,200	MAIN 1360
999	CALL DUMF	MAIN 1370
200	CONTINUE	MAIN 1380
	CALL SECT2	MAIN 1390
	IF (NSTMT-40) 999,300,201	MAIN 1400
201	IF (NSTMT-50) 999,300,202	MAIN 1410
202	IF (NSTMT-60) 999,400,203	MAIN 1420
203	IF (NSTMT-110) 999,700,999	MAIN 1430
300	CONTINUE	MAIN 1440
	CALL SECT3	MAIN 1450
	IF (NSTMT-30) 999,200,301	MAIN 1460
301	IF (NSTMT-70) 999,500,302	MAIN 1470
302	IF (NSTMT-110) 999,500,303	MAIN 1480
303	IF (NSTMT-140) 999,200,404	MAIN 1490
304	IF (NSTMT-161) 999,200,305	MAIN 1500
305	IF (NSTMT-1142) 999,200,999	MAIN 1510
400	CONTINUE	MAIN 1520
	CALL SECT4	MAIN 1530
	IF (NSTMT-10) 999,200,401	MAIN 1540
401	IF (NSTMT-110) 999,700,402	MAIN 1550
402	IF (NSTMT-140) 999,600,403	MAIN 1560
403	IF (NSTMT-161) 999,200,999	MAIN 1570
500	CONTINUE	MAIN 1580
	CALL SECT5	MAIN 1590
	IF (NSTMT-30) 999,200,501	MAIN 1600
501	IF (NSTMT-110) 999,700,502	MAIN 1610
502	IF (NSTMT-239) 999,600,999	MAIN 1620
600	CONTINUE	MAIN 1630
	CALL SECT6	MAIN 1640
	IF (NSTMT-100) 999,500,601	MAIN 1650
601	IF (NSTMT-110) 999,700,602	MAIN 1660
6020	IF (NSTMT-529) 999,400,602	MAIN 1670
602	IF (NSTMT-1490) 999,500,999	MAIN 1680
700	CONTINUE	MAIN 1690
	CALL ZHRCAT	MAIN 1700
	IF (NSTMT-497) 999,800,999	MAIN 1710
800	CONTINUE	MAIN 1720
		MAIN 1730

FILE: TH3 FORTRAN A1 NAVAL POSTGRADUATE SCHOOL

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COMMON    VIALB , VIAL , VIEG , VIBLB , VIBL , VIGM ,    SEC10620
6        VIGMS , VILB , VILM , VILMS , VLM , VLO ,    SEC10640
7        VL , VLSQ , VLS , VS , VSS , VASB ,    SEC10660
8        WAG , WAGS , WAL , WGB , WGBS , WGS ,    SEC10680
9        WBL , WGB , WG , WGS , WIM , WMS ,    SEC10700
COMMON    WMT , WOS , XS , XI , XIA , XCLK ,    SEC10720
1        XMT , XO , XS , XI , XIA , XCLK ,    SEC10740
2        YIS , YO , YOS , ZZZ , NSTMT , YI ,    SEC10760
      DIMENSION PL(10)    SEC10780
      DIMENSION NDRAW(75)    SEC10800
      DIMENSION DATE(5), CASE(3), QID(8), XP(2,75), PL1(10),    SEC10820
1        C(6), AP(2,75), XXA(8), DSRAY(100), DSRAY1(100), TBWAY(100), TBWAYS(100)    SEC10840
21(100), DRAY(75), HT(18), DIA(8)    SEC10860
      EQUIVALENCE (NDRAW(1), DRAY(1))    SEC10880
C        ***** STATEMENT NO. 10 *****    SEC10900
C        *****    SEC10920
C        *****    SEC10940
10 CONTINUE    SEC10960
      NSTMT=9999    SEC10980
C        DO WE HAVE TO WOT (XX=-1.0 IN MAIN) SET (POSSIBLY) IN SECT4    SEC11000
      IF (XX+1.0) 1,2,1    SEC11020
      1 CONTINUE    SEC11040
      WRITE (6,8077) XX    SEC11060
      XX=-1.0    SEC11080
2 CONTINUE    SEC11100
C READ INPUTS AND PRINT HEADING FOR THIS CASE    SEC11120
      READ (5,910,END=777) (DATE(I),I=1,5), (CASE(I),I=1,3), (QID(I),    SEC11140
1I=1,8), NS, NP    SEC11160
      IF (NS) 55,11    SEC11180
99 NSTMT=64    SEC11200
      RETURN    SEC11220
11 CONTINUE    SEC11240
      READ (5,911) MBU,MOP,AGZO,NDS,NSO,NB,NNS    SEC11260
      READ (5,912) DP,PC,PHI,RAKO,EAT,H,ALAM,DP1,    SEC11280
1WAL,WBL,SA,SB,DO,PO,TGO,TLO,VGO,VLO,THOO,THIO,EDS,ZSO,    SEC11300
2EB    SEC11320
      WRITE (6,913) DATE,CASE,QID,NS,NP,    SEC11340
1MBU,MOP,AGZO,NDS,NSO,NB,NNS,DP,PC,PHI,RAKO,EAT,    SEC11360
2H,ALAM,WAL,WBL,SA,SB,DO,PO,TGO,TLO    SEC11380
      WRITE (6,9913) VGO,VLO,THOO,THIO,EDS,ESO,EB,DP1    SEC11400
      NDIAG=0    SEC11420
      MNN=0    SEC11440
      KAP=1    SEC11460
      SACV = 0    SEC11480
      AM=0    SEC11500
      IACV = 0    SEC11520
      KTS = 1    SEC11540
      KDS = 1    SEC11560
      LCT2=0    SEC11580
      K1=1    SEC11600
      K2=1    SEC11620
      KDSCT=0    SEC11640
      KFOCT=0    SEC11660
      NCTS=0    SEC11680
      LC11=10    SEC11700
      K=1    SEC11720
C        GET X(P) TABLE IDENTIFICATION AND X(P) TABLE DATA POINTS.    SEC11740
C        *****    SEC11760
C        *****    SEC11780
14 IF (MOP) 1360,14,1360    SEC11800
      14 READ (5,9914) (XXA(I),I=1,8)    SEC11820
      WRITE (6,9915) (XXA(I),I=1,8)    SEC11840
C        READ IN X(2) TABLE IF MOP=0    SEC11860
      DO 8000 J=1,K2=1,75    SEC11880
      DO 8000 JP=1,2    SEC11900
      XP(JP,K2)=-1.0    SEC11920
8000 CONTINUE    SEC11940
C        *****    SEC11960
9 READ (5,914) (C(L),L=1,6)    SEC11980
      DO 1320 L=1,5,2    SEC12000
      IF (C(L)-C(L+1)) 18,15,18    SEC12020
      18    SEC12040
      15    SEC12060
      18    SEC12080

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1 7A4,A2)
8077 FORMAT(1H0,10X,19HISOTHERMAL FLOW TO ,1DE16.4 , 6H PSIA.)
END

SUBROUTINE SECT2

COMMON TZZZAY

DIMENSION TZZZAY(11200)

THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP

IT MUST BE THE FIRST COMMON BLOCK

C
C

```

COMMON A ADAR ALAM ALHAB ALPHA ALHMB
1 ALPHS AM AP AS AT PA
2 BB BETAB BETAMB BETAS BMB
3 C C1 CAG1 CAGMB CAG CALMB
4 CBG1 CAL CASE CBGMB CHG CBELMB CBL
COMMON CCM CDB CD CPM CPM CPM
6 CCM CCM CCM CCM CCM CCM
7 CLMS CSAVE D D2 DA DATE
8 DD DELIM DELI DELIS DELOM DELV
9 DELOS DELSI DELSO DELT DELV2
COMMON DEMAGB DEMAG DEMAGB DEFBG DFBG DINT
1 DLSIS DO DSI DP DP DRAY
2 DRI DRO DR DS1 DSAY DSAYS1 DSAYS2
3 DSRMAX DSRMIN DSRX1 DSRX2 DTG1 DTG2
4 DSR ES DTHI DTHG DTLB DTLB DTLB
COMMON DT DVB SQ DVB SQ DVB SQ DVB SQ
6 DYO DB DB DB DB DB DB
7 DMBG DBG DBG DBG DBG DBG
8 DML DBL DBL DBL DBL DBL
9 COMMON H HJ HJ HJ HJ HJ
1 HKH HKHMS HLA1 HLA2 HLA3
2 HLB1 HLB HLB HLB HLB
3 HOP H H H H H
4 IJH INT ISCT IZERO K K
COMMON K2 KAP KACT KDS KL KRI
6 KR KTDCT KTB KXF1 KXP L L
7 L1 L2 LCT1 LCT2 LL LPACT
8 LSW LBU LBU LBU LBU LBU
9 COMMON MOP MMT MACV MCB MCB MCB
1 MNDIAG MDS MDS MDS MDS MDS
2 MNA MNA MNA MNA MNA
3 MNSO MNSO MNSO MNSO MNSO
4 PAS PBR PBR PBR PBR PBR
COMMON PBR PBR PBR PBR PBR
6 PL1 PL PL PL PL PL
7 PL PL PL PL PL PL
8 PL PL PL PL PL PL
9 COMMON PEG PEG PEG PEG PEG
1 PHOG PHOG PHOG PHOG PHOG
2 RIM RI RM RM RM
3 ROBL ROM RO RO RO
4 RVS RV RVS RV RVS
COMMON S1 S4 S4 S4 S4
6 SITS SMTH SMJ1 SMJ2 SMLC SMLD
7 SML E SMLF SMLG SMLH SMLI SMLJ
8 SUP SO SUBT SUBT SUBT SUBT
9 T T T T T T
COMMON THO THO THO THO THO
1 THIB THO THO THO THO
2 THMS THO THO THO THO
3 THO THO THO THO THO
4 VDS VDS VDS VDS VDS
COMMON VIALB VIAL VIAL VIAL VIAL
6 VIGMS VIAL VIAL VIAL VIAL
7 VL VL VL VL VL
8 VAG VAG VAG VAG VAG
9 COMMON VBL VBL VBL VBL VBL
1 XNT XP XS XX XNA XI
2 YIS YO YOS YOS YOS YOS
DIMENSION PL(10)

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SEC12120
SEC12130
SEC12140
SEC12150
SEC12160
SEC12170
SEC12180
SEC12190
SEC12200
SEC12210
SEC12220
SEC12230
SEC12240
SEC12250
SEC12260
SEC12270
SEC12280
SEC12290
SEC12300
SEC12310
SEC12320
SEC12330
SEC12340
SEC12350
SEC12360
SEC12370
SEC12380
SEC12390
SEC12400
SEC12410
SEC12420
SEC12430
SEC12440
SEC12450
SEC12460
SEC12470
SEC12480
SEC12490
SEC12500
SEC12510
SEC12520
SEC12530
SEC12540
SEC12550
SEC12560
SEC12570
SEC12580
SEC12590
SEC12600
SEC12610
SEC12620
SEC12630
SEC12640
SEC12650
SEC12660
SEC12670
SEC12680
SEC12690
SEC12700


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        DIMENSION NDRAW(75)
        DIMENSION DATE(5), CASE(3), QID(8), XP(2,75), PL1(10)
1      C(6), AP(2,75), XXA(8), DSRAY(100), DSRAY1(100), TBAY(100), TBAY1(100)
21(100), DRAY(75), HT(18), DIST(8)
EQUIVALENCE (NDRAW(1), DRAY(1))
IF(NSTMT-30) 1,30,2
1 CALL DUMPE
2 IF(NSTMT-145) 1,145,3
3 IF(NSTMT-161) 1,161,4
4 IF(NSTMT-1142) 1,1142,5
5 CONTINUE

C SET ITERATION COUNT ZERO
C
C   NNA=0
C
C SET INITIAL CONDITIONS INDICATION
C
C ***** STATEMENT NO. 20 *****
C *****
20 NFP=1
  MEPO=1
  IBLX=0
  KAP=1
  NNN=0
  BO=0.0
  PHI=PHI*0.01745329
  AT=100000.0

C INITIALIZE PRINTOUT COUNT
C
C   NNP=1
C
C SETUP MIDPOINT AND ENDPOINT INDICATION.
C   INT = 1, NEXT ENTRY TO STATEMENT 32 COMPUTES MIDPOINT
C   QUANTITIES.
C   INT = 0, NEXT ENTRY TO STATEMENT 32 COMPUTES ENDPOINT
C   QUANTITIES.
C   INT=1
C
C RESET THROAT INDICATOR
C   NTHT = 0 - THROAT NOT REACHED
C   NTHT = 1 - THROAT REACHED
C   NTHT=0
C
C RESET DS ITERATION COUNTER.
C
C   NNDS=0
C
C RESET OPTIMUM S ITERATION COUNTER.
C
C   NNSO=0
C
C BACKSTEP P FOR FIRST ENTRY TO 30
C
C   P= PO-OP1/2.0
C
C SETUP INITIAL CONDITIONS
C
C   TG=TGO
C   TL=TL0
C   VG=VGO
C   VL=VLO
C   D=DO
28 X=0.
27 DTL=0.0
  DS1=0.
  E=0.
  DTG=0.0
  AT=0.

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SBC 20710
SBC 20720
SBC 20730
SBC 20740
SBC 20750
SBC 20760
SBC 20770
SBC 20780
SBC 20790
SBC 20800
SBC 20810
SBC 20820
SBC 20830
SBC 20840
SBC 20850
SBC 20860
SBC 20870
SBC 20880
SBC 20890
SBC 20900
SBC 20910
SBC 20920
SBC 20930
SBC 20940
SBC 20950
SBC 20960
SBC 20970
SBC 20980
SBC 20990
SBC 21000
SBC 21010
SBC 21020
SBC 21030
SBC 21040
SBC 21050
SBC 21060
SBC 21070
SBC 21080
SBC 21090
SBC 21100
SBC 21110
SBC 21120
SBC 21130
SBC 21140
SBC 21150
SBC 21160
SBC 21170
SBC 21180
SBC 21190
SBC 21200
SBC 21210
SBC 21220
SBC 21230
SBC 21240
SBC 21250
SBC 21260
SBC 21270
SBC 21280
SBC 21290
SBC 21300
SBC 21310
SBC 21320
SBC 21330
SBC 21340
SBC 21350
SBC 21360
SBC 21370
SBC 21380
SBC 21390
SBC 21400
SBC 21410
SBC 21420
SBC 21430

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```

      VGSQ=VG*VG
      VLSQ=VL*VL
      THO=THOQ
      THI=THIQ
      DELT=TG-TL
      DELV2=VGSQ-VLSQ
      DS1=0.
      R=0.
      DTHO=0.0
      DTHI=0.0
      ***** STATEMENT NO. 30 *****
30  NSTMT=9999
    IP(MFP) 631,630,630
      THIS IS FIRST POINT - HALF STEP P BY INITIAL DP STEP-SIZE.
631  P=P+DP1/2.0
    GO TO 632
      THIS IS NOT FIRST POINT - HALF STEP PRESSURE BY STEP
      SIZE DP.
630  P=P+DP/2.0
632  IF(P) 1130,1130,131
      STEPPING PRESSURE MADE IT NEGATIVE - PRINT DIAGNOSTIC, AND
      DATA COMPUTED TO THIS POINT AND GO TO NEXT CASE.
1130 WRITE (6,930)
     LL=1
     GO TO 500
      EXTRAPOLATE TG AND TL, PRINT DIAGNOSTICS IF THEY GO
      NEGATIVE, AND PRINT DATA COMPUTED TO THIS POINT.
131  CONTINUE
     TG=TG+DTG/2.0
     IF(TG) 132,132,133
132  WRITE (6,931)
     LL=2
     GO TO 500
133  TL=TL+DTL/2.0
     IF(TL) 134,134,135
134  WRITE (6,932)
     LL=3
     GO TO 500
      INTERPOLATE FOR PBO FOR THIS TL
135  N=9
     NN=9
     CALL INTER(PBO,N,TL,P)
     IF(N) 136,135,137
136  WRITE (6,9136) HT(NN),TL,P
     LL=1
     GO TO 500
      CHECK DENOMINATOR OF EQUATION FOR PARTIAL PRESSURE
      OF COMPONENT A, PRINT DIAGNOSTIC IF SUFFICIENTLY
      CLOSE TO ZERO RENDERING PA INFINITE.
137  IF(ABS(1.0-H*PBO)-.0001) 138,138,139
138  WRITE (6,933)
     LL=3
     GO TO 500
139  PA=(P-PBO)/(1.0-H*PBO)
      COMPUTE PA AND PB. IF EITHER IS NEGATIVE, PRINT
      DIAGNOSTIC AND GO TO NEXT CASE.

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SEC2 1440
SEC2 1450
SEC2 1460
SEC2 1470
SEC2 1480
SEC2 1490
SEC2 1500
SEC2 1510
SEC2 1520
SEC2 1530
SEC2 1540
SEC2 1550
SEC2 1560
SEC2 1570
SEC2 1580
SEC2 1590
SEC2 1600
SEC2 1610
SEC2 1620
SEC2 1630
SEC2 1640
SEC2 1650
SEC2 1660
SEC2 1670
SEC2 1680
SEC2 1690
SEC2 1700
SEC2 1710
SEC2 1720
SEC2 1730
SEC2 1740
SEC2 1750
SEC2 1760
SEC2 1770
SEC2 1780
SEC2 1790
SEC2 1800
SEC2 1810
SEC2 1820
SEC2 1830
SEC2 1840
SEC2 1850
SEC2 1860
SEC2 1870
SEC2 1880
SEC2 1890
SEC2 1900
SEC2 1910
SEC2 1920
SEC2 1930
SEC2 1940
SEC2 1950
SEC2 1960
SEC2 1970
SEC2 1980
SEC2 1990
SEC2 2000
SEC2 2010
SEC2 2020
SEC2 2030
SEC2 2040
SEC2 2050
SEC2 2060
SEC2 2070
SEC2 2080
SEC2 2090
SEC2 2100
SEC2 2110
SEC2 2120
SEC2 2130

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      IF (PA) 439,440,440
439  WRITE (6,5439)
      LL=4
      GO TO 500
440  PB=P-PA
      IF (PB) 441,442,442
441  WRITE (6,5440)
      LL=5
      GO TO 500
C
C      INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT A
C      GAS TABLE AT TEMPERATURE TG.
C
442  N=3
      NN=3
      CALL INTERP(WAG,N,TG,PA)
      IF (N) 1141,1141,143
1141  LL=5
1142  WRITE (6,9136) HT(NN),TG,PA
      NSTMT=9999
      GO TO 500
C
C      INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT B
C      GAS TABLE AT TEMPERATURE TG.
C
143  N=4
      NN=4
      CALL INTERP(WBG,N,TG,PB)
      IF (N) 144,144,150
144  LL=6
145  WRITE (6,9136) HT(NN),TG,PB
      NSTMT=9999
      GO TO 500
C
C      COMPUTE MEAN MOLECULAR WEIGHT OF GAS MIXTURE.
C
150  WG=(WAG*PA+WBG*PB)/P
C
C      COMPUTE RATIO OF FLOW RATE OF LIQUID A TO FLOW
C      RATE OF LIQUID MIXTURE OF A AND B - ALPHA
C
      ALPHA=((WAL/WBL)*H*PA)/(1.0+((WAL/WBL)-1.0)*H*PA)
C
C      COMPUTE RATIO OF FLOW RATE OF GAS B TO FLOW RATE
C      OF GAS MIXTURE OF A AND B - BETA
C
      BETA=(WBG*PB)/(WG*P)
C
C      COMPUTE RATIO OF FLOW RATE OF LIQUID MIXTURE TO
C      FLOW RATE OF GAS MIXTURE, R. CHECK DENOMINATOR OF
C      EQUATION FOR R AND PRINT DIAGNOSTIC IF SUFFICIENTLY
C      CLOSE TO ZERO.
C
      IF (ABS(1.0-(1.0+RC)*ALPHA)-.0001) 151,152,152
151  WRITE (6,9151)
      LL=7
      GO TO 500
152  DR=((RC-(1.0+RC)*BETA)/(1.0-(1.0+RC)*ALPHA))-R
      R=R+DR
C
C      COMPUTE GAS DENSITY - RHOG
C
      RHOG=(WG*P)/(TG*10.732)
C
C      INTERPOLATE IN TABLE FOR DENSITY OF LIQUID A AT THIS
C      TEMPERATURE.
C
      N=10
      NN=10
      CALL INTERP(ROAL,N,TL,P)
      IF (N) 160,160,162
C

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      ETC 2 2140
      ETC 2 2150
      ETC 2 2160
      ETC 2 2170
      ETC 2 2180
      ETC 2 2190
      ETC 2 2200
      ETC 2 2210
      ETC 2 2220
      ETC 2 2230
      ETC 2 2240
      ETC 2 2250
      ETC 2 2260
      ETC 2 2270
      ETC 2 2280
      ETC 2 2290
      ETC 2 2300
      ETC 2 2310
      ETC 2 2320
      ETC 2 2330
      ETC 2 2340
      ETC 2 2350
      ETC 2 2360
      ETC 2 2370
      ETC 2 2380
      ETC 2 2390
      ETC 2 2400
      ETC 2 2410
      ETC 2 2420
      ETC 2 2430
      ETC 2 2440
      ETC 2 2450
      ETC 2 2460
      ETC 2 2470
      ETC 2 2480
      ETC 2 2490
      ETC 2 2500
      ETC 2 2510
      ETC 2 2520
      ETC 2 2530
      ETC 2 2540
      ETC 2 2550
      ETC 2 2560
      ETC 2 2570
      ETC 2 2580
      ETC 2 2590
      ETC 2 2600
      ETC 2 2610
      ETC 2 2620
      ETC 2 2630
      ETC 2 2640
      ETC 2 2650
      ETC 2 2660
      ETC 2 2670
      ETC 2 2680
      ETC 2 2690
      ETC 2 2700
      ETC 2 2710
      ETC 2 2720
      ETC 2 2730
      ETC 2 2740
      ETC 2 2750
      ETC 2 2760
      ETC 2 2770
      ETC 2 2780
      ETC 2 2790
      ETC 2 2800
      ETC 2 2810
      ETC 2 2820
      ETC 2 2830
      ETC 2 2840
      ETC 2 2850

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CC TABLE LIMITS EXCEEDED - WRITE DIAGNOSTIC.
160 LL=8
161 WRITE (6,2136) HT(NN),TL,P
   NSTMT=4989
   GO TO 500
CC INTERPOLATE IN TABLE FOR DENSITY OF LIQUID B AT THIS
   TEMPERATURE.
162 N=11
   NN=11
   CALL INTERP(ROBL,N,TL,P)
   IF(N) 161,161,163
CC COMPUTE DENSITY OF LIQUID MIXTURE
163 RHOL=1.0/((ALPHA/POAL)+(1.0-ALPHA)/ROBL)
CC COMPUTE FLOW RATES OF LIQUID MIXTURE AND OF GAS MIXTURE.
   ENG=ENT/(1.0+R)
   EML=R*ENG
CC COMPUTE RATIO OF GAS VOLUME FLOW TO LIQUID VOLUME FLOW.
   PV=RHOL/(R*RHOGL)
CC INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
   THIS TEMPERATURE AND PRESSURE.
   N=1
   NN=1
   CALL INTERP(CAG,N,TG,PA)
   IF(N) 165,165,170
165 LL=9
   GO TO 1142
170 N=2
   NN=2
   CALL INTERP(CBG,N,TG,PB)
   IF(N) 145,145,171
CC INTERPOLATE INTO LATENT HEAT OF VAPORIZATION TABLES
   FOR A AND B AT THIS TEMPERATURE.
171 N=7
   NN=7
   CALL INTERP(HLA,N,TL,P)
   LL=9
   IF(N) 161,161,172
172 N=8
   NN=8
   CALL INTERP(HLB,N,TL,P)
   LL=10
   IF(N) 161,161,31
31 IF(MED-1) 32,40,32
32 IF(IT-1) 60,50,60
40 NSTMT=40
   RETURN
50 NSTMT=50
   RETURN
60 NSTMT=60
   RETURN
500 NDIAG=1
   CALL OUTPUT(NNN,LPGCT,MGEO)
   NSTMT=110
   RETURN
930 FORMAT(1H0,7X,13HNONPOSITIVE P)
931 FORMAT(1H0,7X,14HNONPOSITIVE TG)
932 FORMAT(1H0,7X,14HNONPOSITIVE TL)
933 FORMAT(1H0,7X,11HINFINITE PA)
936 FORMAT(1H0,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,

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SEC2 22860
SEC2 22870
SEC2 22880
SEC2 22890
SEC2 22900
SEC2 22910
SEC2 22920
SEC2 22930
SEC2 22940
SEC2 22950
SEC2 22960
SEC2 22970
SEC2 22980
SEC2 22990
SEC2 23000
SEC2 23010
SEC2 23020
SEC2 23030
SEC2 23040
SEC2 23050
SEC2 23060
SEC2 23070
SEC2 23080
SEC2 23090
SEC2 23100
SEC2 23110
SEC2 23120
SEC2 23130
SEC2 23140
SEC2 23150
SEC2 23160
SEC2 23170
SEC2 23180
SEC2 23190
SEC2 23200
SEC2 23210
SEC2 23220
SEC2 23230
SEC2 23240
SEC2 23250
SEC2 23260
SEC2 23270
SEC2 23280
SEC2 23290
SEC2 23300
SEC2 23310
SEC2 23320
SEC2 23330
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SEC2 23360
SEC2 23370
SEC2 23380
SEC2 23390
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SEC2 23420
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SEC2 23460
SEC2 23470
SEC2 23480
SEC2 23490
SEC2 23500
SEC2 23510
SEC2 23520
SEC2 23530
SEC2 23540
SEC2 23550
SEC2 23560
SEC2 23570

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2      DIMENSION YIS , YO , YOS , ZZZ , NSTMT
      DIMENSION NDRAW(75)
      DIMENSION DATE(5), CASE(3), OID(8), XP(2,75), PL1(10),
1      C(6), AP(2,75), XXA(8), DSRAY(100), DSRAY1(100), TBAY(100), TBAY1(100),
21(100), DBAY(75), HT(18), DINT(8)
      EQUIVALENCE (NDRAW(1), DRAW(1))
      IF (NSTMT-40) 1,40,2
1      CALL DUMP
2      IF (NSTMT-50) 1,50,1
C
C      THIS IS FIRST POINT - STORE INITIAL PROPERTIES FOR USE
C      AT END OF FIRST INTERVAL.
C
C      ***** STATEMENT NO. 40 *****
C
40      APP=0
      NSTMT=9999
      HLA1=HLA
      HLB1=HLB
      CAG1=CAG
      CBG1=CBG
C
C      COMPUTE INITIAL FLOW RATES OF COMPONENTS A AND B.
C
      EMAG=(EMG*WAG*PA)/(WG*P)
      EMBG=(EMG*WBG*PB)/(WG*P)
      DR=0.
      IF (VG) 175,175,174
174      IF (VI) 175,175,176
175      A=1000.000.
      RA=A
      GO TO 41
C
C      COMPUTE INITIAL AREA OF NOZZLE.
C
176      A=144.*EMG*((1.0/(RHOG*VG))+(R/(RHOL*VL)))
      RA=PV*VL/VG
41      AT=A
      PT=P
      AP(1,1)=P
      AP(2,1)=A
      KAP=2
C
C      COMPUTE SLIP VELOCITY, VS, MEAN FREE STREAM VELOCITY, V8, AND
C      SLIP FRACTION, S.
C
42      VS=VG-VL
      VB=(VG+R*VL)/(1.0+R)
      VBSO=VP*VB
      S=VS/VB
      IF (GEO) 180,179,180
C
C      NOZZLE IS CIRCULAR - COMPUTE DISTANCE FROM NOZZLE AXIS TO
C      WALL OF NOZZLE, YI.
C
179      YO=SQRT(A/3.1416)
      YI=0.
      RI=0.0
      GO TO 43
C
C      NOZZLE IS ANNULAR - COMPUTE RADII AND DISTANCES TO WALL
C      OF ANNULAR NOZZLE, RI,RO,YI,YO.
C
180      TST=(RAXC**2)-((A*COS(PHI))/(2.0*3.1416))
      IF (TST) 181,182,182
181      R1T=(5.9191)
      LL=11
      GO TO 500
182      RI=SQRT(IST)
      RO=(RAXC**2)+((A*COS(PHI))/(2.0*3.1416))
      RO=SQRT(RO)

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      YI=(YAXO-HI)/COS(PHI)
      YO=(YO-HAXO)/COS(PHI)
C
C WRITE LINES 1,2,3 OF OUTPUT AND GO TO 30.
C
43 IF (LCT1-42) 644,643,643
643 LCT1=0
      WRITE (6,9643) LPGCT
      LPGCT=LPGCT+1
644 WRITE (5,1001) X,P,R,V3,A,TG,TL,VG,VL
      WRITE (6,1002) VS,S,D,d7,RA,ALPHA,BETA,ENG,ENL
      WRITE (5,1003) RHOG,RHOL,WAG,WBG,WA,PA,PB,HLA,HLB
      LCT1=LCT1+9
      GO TO 30
C
C MIDPOINT OF INTERVAL - COMPUTE MID-POINT PARAMETERS.
C RESET MIDEPOINT/ENDPOINT INDICATOR SO NEXT ENTRY TO 32
C WILL BE AN ENDPOINT.
C
C ***** STATEMENT NO. 50 *****
50 INT=0
      NST=9999
C
C INTERPOLATE IN VISCOSITY (GAS) TABLES FOR A AND B AT
C THIS GAS TEMPERATURE.
      N=16
      NN=16
      CALL INTER(VIAG,N,TG,PA)
      IF (N) 205,205,206
205 LL=12
      GO TO 1142
206 N=17
      NN=17
      CALL INTER(VIBG,N,TG,PB)
      IF (N) 207,207,208
207 LL=13
      GO TO 145
C
C INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
C THIS LIQUIDS TEMPERATURE.
208 N=5
      NN=5
      CALL INTRP(CAL,N,TL,P)
      LL=12
      IF (N) 161,161,209
209 NN=6
      N=6
      CALL INTRP(CBL,N,TL,P)
      LL=12
      IF (N) 161,161,210
C
C COMPUTE MEAN SPECIFIC HEATS OF LIQUID, CLM, AND OF
C GAS, CGM.
210 CLM=ALPHA*CAL+(1.0-ALPHA)*CBL
      CGM=(1.0-BETA)*CAG+BETA*CBG
      PHIAB=((1.0+((VIAG/VIBG)**.5))*((WBG/WAG)**.25))**.2)/
      (2.828*((1.0+WAG/WBG)**.5))
      PHIBA=((1.0+((VIBG/VIAG)**.5))*((WAG/WBG)**.25))**.2)/
      (2.828*((1.0+WBG/WAG)**.5))
C
C COMPUTE MEAN VISCOSITY OF A AND B GAS.
      VIGM=(VIAG/((1.0+(BETA/(1.0-BETA))*(WAG/WBG)*PHIAB)))+
      (VIBG/((1.0+(((1.0-BETA)/BETA)*(WBG/WAG)*PHIBA))))
C
C INTERPOLATE IN VISCOSITY (LIQUID) TABLES FOR A AND B AT
C THIS TEMPERATURE.

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```

N=14
NN=14
CALL INTER(VIAL,N,TL,P)
LL=13
IF(N) 161,161,215
215 N=15
NN=15
CALL INTER(VIBL,N,TL,P)
LL=13
IF(N) 161,161,216

CCCC COMPUTE MEAN THERMAL CONDUCTIVITY OF GAS MIXTURE, HKGM.
BA AND BB ARE USED SUBSEQUENTLY IN DETERMINING HKGM.
CCCC
216 VILM=ALPHA*VIAL*(1.0-ALPHA)*VIBL
T1=(SQRT(SA*SB)/TG+1.0)*0.25
T2=1.0+SA/TG
T3=1.0+SB/TG
T4=T2/T3
T5=(WAG/WBG)**0.75
T6=VILM/VIBL
T7=SQRT(T6*T4*T5)
BA=T1/T2*(1.0+T7)**2
BB=T1/T3*(1.0+1.0/T7)**2

CCCC INTERPOLATE IN THERMAL CONDUCTIVITY TABLES FOR COMPONENTS
A AND B IN GASEOUS STATE.
CCCC
N=12
NN=12
CALL INTER(HKAG,N,TG,P)
LL=13
IF(N) 145,145,220
220 N=13
NN=13
CALL INTER(HKBG,N,TG,P)
LL=13
IF(N) 145,145,221

CCCC IF BETA=1, FIRST TERM OF HKGM IS SET=0
IF BETA=0, SECOND TERM OF HKGM IS SET=0
CCCC
221 IF(BETA-1.0) 223,222,223
222 HKGM1=0.0
GO TO 224
223 HKGM1=HKAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*BA)
224 IF(BETA) 225,225,226
225 HKGM2=1.0
GO TO 227
226 HKGM2=HKBG/(1.0+((1.0+BETA)/BETA)*(WBG/WAG)*BB)
227 HKGM=HKGM1+HKGM2

CCCC COMPUTE V1,V2,R1, HERE FOR USE IN ITERATIVE LOOP AT
STATEMENT NO. 70.
CCCC
V1=((99443.6*TG)/((1.0+R)*WG))*ALOG
1 V2=((P*DP/2.0)/(P-DP/2.0))
V2=(9366.00*V*DE)/((1.0+R)*RHOL)
R1=(300.0*RHOG*V)/VILM
IF(MOP) 51,52,51

CCCC OPTIMUM X (F) IS TO BE USED.
CCCC
***** STATEMENT NO. 51 *****
51 C1=(D*ALAM*RHOL)/(9.0*RHOG)
S*LG=R/((1.0+R)**2)
16070 KDS=1
KDSCT=0
NNSO=0
NNSOO=0
DSAIN=-2.*(S*(1.0+R)/R)+1.0E-06

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SEC3 2120
SEC3 2110
SEC3 2140
SEC3 2150
SEC3 2160
SEC3 2170
SEC3 2180
SEC3 2190
SEC3 2200
SEC3 2210
SEC3 2220
SEC3 2230
SEC3 2240
SEC3 2250
SEC3 2260
SEC3 2270
SEC3 2280
SEC3 2290
SEC3 2300
SEC3 2310
SEC3 2320
SEC3 2330
SEC3 2340
SEC3 2350
SEC3 2360
SEC3 2370
SEC3 2380
SEC3 2390
SEC3 2400
SEC3 2410
SEC3 2420
SEC3 2430
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SEC3 2480
SEC3 2490
SEC3 2500
SEC3 2510
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SEC3 2580
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SEC3 2630
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SEC3 2690
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SEC3 2750
SEC3 2760
SEC3 2770
SEC3 2780
SEC3 2790
SEC3 2800
SEC3 2810
SEC3 2820
SEC3 2830

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      DSMAX = 1.0 + R - 1.0E-06
      GO TO 70
C
C SPECIFIED X(P) IS TO BE USED.
52 P10=P+DP/2.0
   P11=P-DP/2.0
   PINT=P10
   KL=1
1152 GO TO 1100
      X10=XINT
      PINT=P11
      KL=2
1153 GO TO 1100
      X11=XINT
C
C GET DIFFERENCE OF INTERPOLATED X VALUES FROM
C X(P) TABLE
      DX=X10-X11
      S1=(0.75*RHOG*(1.0+R)*DX)/(D*RHOL)
      S2=(4633.04*(1.0+R)*DP)/RHOL
      S3=(1.0+R)/2.0
      S4=2.0*DS/(1.0+R)
      GO TO 16070
C
C INTERPOLATE INTO X(P) TABLE FOR TWO PRESSURE VALUES
C AT EITHER SIDE OF CURRENT INTERVAL.
1100 CONTINUE
C THIS CHANGE TO ALLOW FOR MONOTONIC INCREASING OR DECREASING TABLES
      TERZ=PINT-XP(1,1)*1.0E-5
      IF (TERZ*(XP(1,1)-XP(1,2))) 1106,1102,1105
1106 CONTINUE
      DO 1101 KR=2,KXP1
      TERY=XP(1,KR)-PINT
      IF (TERY*TERZ) 1101,1104,1104
1101 TERY=-TERY
1103 CONTINUE
      GO TO 1120
1102 CONTINUE
      KR=2
1104 KR1=KR-1
      XINT=XP(2,KR1)+TERZ/(XP(1,KR)-XP(1,KR1))*(XP(2,KR)-XP(2,KR1))
      GO TO (1152,1153),KL
1105 CONTINUE
      IF (TERZ-0.001) 1108,1120,1120
1108 IF (TERZ+0.001) 1120,1120,1110
1110 TERY=-1.00*TERZ
      GO TO 1106
1120 *PRINT(6,9105) P10,P11,XL,TERZ,TERY,PINT
      *L=14
      GO TO 500
30 NSTMT=30
   RETURN
1142 NSTMT=1142
   RETURN
145 NSTMT=145
   RETURN
161 NSTMT=161
   RETURN
70 NSTMT=70
   RETURN
500 NDIAG=1
   CALL OUTPUT(NNN,LPGCT,NCEO)
   NSTMT=110
   RETURN
C
C FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
12HTL,12X,2HVG,12X,2HVL,/,6X,1P9E14.4)

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SEC3 27450
SEC3 27460
SEC3 27470
SEC3 27480
SEC3 27490
SEC3 27500
SEC3 27510
SEC3 27520
SEC3 27530
SEC3 27540
SEC3 27550
SEC3 27560
SEC3 27570
SEC3 27580
SEC3 27590
SEC3 27600
SEC3 27610
SEC3 27620
SEC3 27630
SEC3 27640
SEC3 27650
SEC3 27660
SEC3 27670
SEC3 27680
SEC3 27690
SEC3 27700
SEC3 27710
SEC3 27720
SEC3 27730
SEC3 27740
SEC3 27750
SEC3 27760
SEC3 27770
SEC3 27780
SEC3 27790
SEC3 27800
SEC3 27810
SEC3 27820
SEC3 27830
SEC3 27840
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SEC3 27860
SEC3 27870
SEC3 27880
SEC3 27890
SEC3 27900
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SEC3 27960
SEC3 27970
SEC3 27980
SEC3 27990
SEC3 28000
SEC3 28010
SEC3 28020
SEC3 28030
SEC3 28040
SEC3 28050
SEC3 28060
SEC3 28070
SEC3 28080
SEC3 28090
SEC3 28100
SEC3 28110
SEC3 28120
SEC3 28130
SEC3 28140
SEC3 28150
SEC3 28160
SEC3 28170
SEC3 28180
SEC3 28190
SEC3 28200
SEC3 28210
SEC3 28220
SEC3 28230
SEC3 28240
SEC3 28250
SEC3 28260
SEC3 28270
SEC3 28280
SEC3 28290
SEC3 28300
SEC3 28310
SEC3 28320
SEC3 28330
SEC3 28340
SEC3 28350
SEC3 28360
SEC3 28370
SEC3 28380
SEC3 28390
SEC3 28400
SEC3 28410
SEC3 28420
SEC3 28430
SEC3 28440
SEC3 28450
SEC3 28460
SEC3 28470
SEC3 28480
SEC3 28490
SEC3 28500
SEC3 28510
SEC3 28520

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COMMON VIALD , VIAL , VISC , VIBLB , VIBL , VIGN , SEC40670
6 VIGMS , VILB , VILM , VILMS , VLM , VLO , SEC40680
7 VL , VLSQ , VLS , VS , VSS , WATB , SEC40690
8 WAS , WAGS , WAL , WGBB , WGG , WBS , SEC40700
9 WEL , WGB , WG , WGS , WIM , WIMS , SEC40710
COMMON WGM , X , X10 , X11 , XCLK , SEC40720
1 XINT , XP , XS , XX , XKA , YI , SEC40730
2 YIS , YO , YOS , ZZZ , NSTMT , SEC40740
DIMENSION PL(10) SEC40750
DIMENSION DRAY(75) SEC40760
DIMENSION DATE(5) , CASE(3) , QID(4) , KP(2,75) , PL1(10) , SEC40770
1 C(6) , AF(2,75) , XAA(8) , DSRAY(100) , DSRAY1(100) , TBRAY(100) , TBRAY1(100) SEC40780
21(100) , TRAY(75) , HT(18) , DINT(3) SEC40790
EQUIVALENCE (NSRAY(1) , DRAY(1)) SEC40800
IF (NSTMT-60) 1,60,2 SEC40810
1 CALL DDE SEC40820
2 IF (NSTMT-63) 1,63,1 SEC40830
END POINT OF THIS INTERVAL OF PRESSURE. SEC40840
COMPUTE CHANGES IN FLOW PARAMETERS THIS INTERVAL. SEC40850
***** STATEMENT NO. 60 ***** SEC40860
***** SEC40870
60 INT=1 SEC40880
NSTMT=9999 SEC40890
VB=ABS (SQRT(VDSQ)) SEC40900
COMPUTE NEW SLIP FRACTION, S, AND NEW DISTANCE, X. SEC40910
IF (MFPD-1) 4001,4000,4001 SEC40920
4000 S=SM SEC40930
GO TO 4002 SEC40940
4001 S=S*DS SEC40950
4002 X=X+DX SEC40960
COMPUTE CHANGES IN SQUARE OF GAS AND LIQUID VELOCITIES. SEC40970
DVGSQ=((1.0+(R*S)/(1.0+R))**2)*VBSQ-VGSQ SEC40980
DVLSQ=((1.0-S/(1.0+R))**2)*VBSQ-VLSQ SEC40990
COMPUTE CHANGES IN GAS AND LIQUID FLOW RATES. SEC401000
DEMG=(EMG*WAG*PA)/(W*P)-EMAG SEC401010
DEMLG=(EMG*WBG*PB)/(W*P)-EMAG SEC401020
COMPUTE CHANGES IN GAS AND LIQUID TEMPERATURES. SEC401030
DTL=(1.0/CLM)*((H*DELTN*DX)/(600.0*D*RHOLM*VLM)) SEC401040
1 DTL=- (HIA*DEMG/RLM)-(HLE*DEML/ELM) SEC401050
DELT=TG-TL SEC401060
DTG=(-1.0/CLM)*((DVGSQ/50072.3)+1* SEC401070
1 CLM*DTL+DT/(5.4030*RHOLM)*DVLSQ/50072.3)+ SEC401080
2 ((DEMG+DEML)*DELT/2)/(50072.3*EMG)* SEC401090
3 ((HIA+CAG)*DELT)*DEMG+(HLE+CBL)*DELT)* SEC401100
4 DEMLG/EMG SEC401110
IF ((1.0+(R*CLM/CGM))*(H*DX)/(600.0*D*CLM*RHOL SEC401120
1 M*VLM))-1.) 8075,8076,8076 SEC401130
8076 DTL=2. SEC401140
DTG=2.0 SEC401150
IF (P-1.5*PO) 8075,8074,8074 SEC401160
8074 CONTINUE SEC401170
THIS LAST TEST ADDED TO DELETE NEXT TEST AT END OF NOZZLE SEC401180
XX=P SEC401190
CHANGE TO SAVE THE LAST P FOR PRINTOUT IN SECT1. SEC401200
8075 CONTINUE SEC401210
COMPUTE NEW TEMPERATURES FOR LIQUID AND GAS. SEC401220
IF EITHER IS NEGATIVE PRINT DIAGNOSTIC AND EXIT SEC401230
TO NEXT CASE. SEC401240
VGSQ=VGSQ+DVGSQ SEC401250
IF (VGSQ) 230,230,231 SEC401260
230 WRITE (6,9230) SEC401270
LL=15 SEC401280
SEC401290
SEC401300

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GO TO 500
231 VLSQ=VLSQ+DVLSQ
IF (VLSQ) 232, 232, 233
232 *RITE (6,9232)
LL=15
GO TO 500

C
C
C COMPUTE NEW VELOCITIES FOR LIQUID AND GAS.
C
233 VG=ABS (SQRT (VGSQ))
VL=ABS (SQRT (VLSQ))

C
C COMPUTE RATIO OF GAS FLOW AREA TO LIQUID FLOW AREA.
C
RA=RV*(VL/VG)

C
C COMPUTE NEW LIQUID AND GAS FLOW RATES.
C
EMAG=EMAG+DEEMAG
EENG=EENG+DEEENG
DELV2=VGSQ-VLSQ

C
C SET UP INITIAL QUANTITIES FOR NEXT END-POINT.
C
DTL1=DTL
DTG1=DTG
HLA1=HLA
HLB1=HLB
DELT=T2-TL
CAG1=CAG
CEG1=CEG
VS=S*VB

C
C INTERPOLATE INTO SURFACE TENSION TABLE AT THIS LIQUID
C TEMPERATURE.
C
N=19
NH=19
CALL INTER (SIG,N,TL,2)
LL=16
IF (N) 161,161,240
C IF DROPLET BREAKUP OPTION SPECIFIED, COMPUTE DROPLET
C DIAMETER.
240 IF (N-1) 243, 238, 243
238 D2=(.3174*SIG)/(FROG*VS**2)
IF (N-2) 243, 243, 239
239 D=D2

C
C COMPUTE CHANGE IN NOZZLE CROSS-SECTIONAL AREA SINCE
C LAST END-POINT.
C
243 DA=144.0*ENG*(1.0/(RHOG*VG)+R/(RHO*VL))-A

C
C COMPUTE MEAN AREA BETWEEN THIS AND PREVIOUS ENDPPOINT.
C
AM=A+DA/2.0

C
C COMPUTE PRESENT AREA
C
A=A+DA
IF (MGEO-1) 67,68,67

C
C COMPUTE RADII AND DISTANCE FROM AXIS TO WALL OF
C CIRCULAR NOZZLE.
C ***** STATEMENT NO. 67 *****
67 DYO=SQRT (A/3.1416)-YO
RCH=YO+DYO/2.0
DRO=DYO
YO=YO+DYO
RO=YO

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SEC4 1140
SEC4 1150
SEC4 1160
SEC4 1170
SEC4 1180
SEC4 1190
SEC4 1200
SEC4 1210
SEC4 1220
SEC4 1230
SEC4 1240
SEC4 1250
SEC4 1260
SEC4 1270
SEC4 1280
SEC4 1290
SEC4 1300
SEC4 1310
SEC4 1320
SEC4 1330
SEC4 1340
SEC4 1350
SEC4 1360
SEC4 1370
SEC4 1380
SEC4 1390
SEC4 1400
SEC4 1410
SEC4 1420
SEC4 1430
SEC4 1440
SEC4 1450
SEC4 1460
SEC4 1470
SEC4 1480
SEC4 1490
SEC4 1500
SEC4 1510
SEC4 1520
SEC4 1530
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SEC4 1550
SEC4 1560
SEC4 1570
SEC4 1580
SEC4 1590
SEC4 1600
SEC4 1610
SEC4 1620
SEC4 1630
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SEC4 1680
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SEC4 1770
SEC4 1780
SEC4 1790
SEC4 1800
SEC4 1810
SEC4 1820
SEC4 1830
SEC4 1840
SEC4 1850
SEC4 1860
SEC4 1870
SEC4 1880
SEC4 1890
SEC4 1900
SEC4 1910
SEC4 1920
SEC4 1930
SEC4 1940
SEC4 1950
SEC4 1960
SEC4 1970
SEC4 1980
SEC4 1990
SEC4 2000
SEC4 2010
SEC4 2020
SEC4 2030
SEC4 2040
SEC4 2050

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```

      WIM=0.0
      DELI=0.0
      DELSI=0.0
      RDELIN=0.0
      CFIM=0.0
      TWIM=0.0
      GO TO 64

CCCC
      COMPUTE GEOMETRY OF ANNULAR NOZZLE AND BOUNDARY-LAYER
      GROWTH AND SHEAR FOR INNER WALL.

      68 RAX=RAXO-X*SIN(PHI)
      IF (RAX**2-(A*COS(PHI))/(2.0*3.1416)) 241,242,242
241  WRITH=(5.9241)
      LG=17
      GO TO 500
242  DRI=SQRT(RAX**2-{A*COS(PHI)})/(2.0*3.1416)}-RI
      DRC=SQRT(RAX**2-{A*COS(PHI)})/(2.0*3.1416)}-RO
      PI=PI+DRI/2.0
      RI=RI+DRI
      ROM=RO+DRO/2.0
      RO=RO+DRC
      DYI=(RAX-RI)/(COS(PHI))-YI
      DYO=(20-RAX)/(COS(PHI))-YO
      YI=YI+DYI
      YO=YO+DYO

CCCC
      COMPUTE ANGLE OF NOZZLE INNER WALL RELATIVE TO AXIS.

      WIM=(ATAN(DYT/DX))
      WIM=57.29578*WIM
246  DTHI=0.5*CFIM*((RM*BN)/(1.0+R**2))*DX-THIN*
      1 TWIM=((1.141*DVBSQ)/VBSQ-DA/AM*DRI/PI)
      THI=(CFI*THOL*VLSQ)/(6559.6*(1.0+RA))
      THI=THI-DTHI
      DELI=1.286*THI
      DELSI=1.2857*THI
69  DTHO=0.5*CFM*((RM*BN)/(1.0+R**2))*DX-THOM*
      1 TWOM=((1.141*DVBSQ)/VBSQ-DA/AM*DRO/ROM)
      THO=(CFM*THOL*VLSQ)/(6559.6*(1.0+RA))
      THO=THO-DTHO
      DELO=1.286*THO
      DELSO=1.2857*THO

CCCC
      COMPUTE ANGLE OF NOZZLE OUTER WALL RELATIVE TO AXIS.

      WOM=ATAN(DYO/DX)
      WOM=57.29578*WOM

CCCC
      COMPUTE MEAN VELOCITY (INCLUDING BOUNDARY LAYER).

251  VBD=VB*(1.0-((2.0*3.1416)/A)*
      1 (DO*THO+RI*THI))
      GO TO 61

CCCC
      IF AREA LESS ZERO, NOZZLE IS CONVERGING AND THROAT HAS
      NOT JUST BEEN PASSED. IF NOT, NOZZLE THROAT MAY
      HAVE JUST BEEN PASSED.

61  IF (A-AT) 66,62,62

CCCC
      ADVANCE STEP COUNT AND RETURN TO STEP 30 IF MAXIMUM
      STEP COUNT NOT REACHED.

62  NNS=NNS+1
      IF (NNS-NS) 30,260,260

CCCC
      INITIALIZE TB AND COUNTERS AND GO TO STEP 140 TO
      COMPUTE FARRER QUANTITIES.

260  TB=TL
      NNS=0

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SEC4 2260
SEC4 2270
SEC4 2280
SEC4 2290
SEC4 2300
SEC4 2310
SEC4 2320
SEC4 2330
SEC4 2340
SEC4 2350
SEC4 2360
SEC4 2370
SEC4 2380
SEC4 2390
SEC4 2400
SEC4 2410
SEC4 2420
SEC4 2430
SEC4 2440
SEC4 2450
SEC4 2460
SEC4 2470
SEC4 2480
SEC4 2490
SEC4 2500
SEC4 2510
SEC4 2520
SEC4 2530
SEC4 2540
SEC4 2550
SEC4 2560
SEC4 2570
SEC4 2580
SEC4 2590
SEC4 2600
SEC4 2610
SEC4 2620
SEC4 2630
SEC4 2640
SEC4 2650
SEC4 2660
SEC4 2670
SEC4 2680
SEC4 2690
SEC4 2700
SEC4 2710

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      NNB=1
      GO TO 140
C
      OUTPUT HAS JUST BEEN PRINTED. RETURN TO STEP 30
      IF ITERATION IS NOT COMPLETED.
C
63  NNP=NNP+1
      NSTMT=3999
      IF (NNP-NF) 30,64,64
C
64  PL1(1)=XS
      PL1(2)=PS
      PL1(3)=RS
      PL1(4)=VES
      PL1(5)=AS
      PL1(6)=TGS
      PL1(7)=TIS
      PL1(8)=VGS
      PL1(9)=VLS
      PL1(10)=1.0
C
      #RITE(18) PL1
264 CALL OUTPUT (NNN,LPGCT,NGEO)
      GO TO 110
66  AT=A
      PT=P
      XS=X
      PS=P
      TIS=TL
      VGS=VG
      RS=R
      VES=VB
      AS=A
      TGS=TG
      VLS=VL
      VGS=VS
      SS=S
      DD=D
      PDS=PV
      PAS=PA
      ALPHS=ALPHA
      BETA=JETA
      PPGS=PG
      EXLS=XL
      PHCGS=PHCG
      RHCLS=RHCL
      WAGS=WAG
      WGG=WG
      WGS=WG
      PAS=PA
      PES=PB
      HLAS=HLA
      HLBS=HLB
      SIGS=SIG
      CGMS=CGM
      CLMS=CLM
      VIGMS=VIGM
      VILMS=VILM
      HKMS=HKM
      REYS=REY
      CDMS=CD
      HMS=HM
      YOS=YO
      WOMS=WOM
      THOS=THO
      DELOS=DELIO
      DLSOS=DLISO
      RDOMS=RDELOM
      CFMS=CFM
      TOMS=TCM
      VBDS=VBD

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      2720
      2710
      2740
      2750
      2760
      2770
      2780
      2790
      2800
      2810
      2820
      2830
      2840
      2850
      2860
      2870
      2880
      2890
      2900
      2910
      2920
      2930
      2940
      2950
      2960
      2970
      2980
      2990
      3000
      3010
      3020
      3030
      3040
      3050
      3060
      3070
      3080
      3090
      3100
      3110
      3120
      3130
      3140
      3150
      3160
      3170
      3180
      3190
      3200
      3210
      3220
      3230
      3240
      3250
      3260
      3270
      3280
      3290
      3300
      3310
      3320
      3330
      3340
      3350
      3360
      3370
      3380
      3390
      3400
      3410
      3420
      3430

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YIS=YI
WIPS=WIM
THIS=THI
DELIS=DELI
DLISIS=DELSI
RDIMS=DELSI
CFIMS=CFIM
T4IDS=WIM
GO TO 62
30 NSTMT=30
RETURN
140 NSTMT=140
RETURN
161 NSTMT=161
RETURN
500 NDIAG=1
CALL OUTPUT(NNN,LPGCT,MGZO)
110 NSTMT=110
RETURN
9230 FORMAT(1H0,7X,14HNONPOSITIVE VG)
9232 FORMAT(1H0,7X,14HNONPOSITIVE VL)
9241 FORMAT(1H0,7X,14HNEGATIVE RI)
END

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COMMON TZZZAY
DIMENSION TZZZAY(11200)
THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
IT MUST BE THE FIRST COMMON BLOCK
C
COMMON
1 ALPHAS / ABAR / ALAM / ALPHAB / ALPHA / ALPHAB
2 BB / BRAB / AB / AB / AB / AB
3 C / C1 / CAG1 / CAGMB / CAG / CALMB
4 CBG1 / CAL / CASE / CBGMB / CBG / COLMB / CRL
COMMON CDMS / CDP / CD / CF1 / COLMS / CROM
6 CIMS / CMB / CCM / CCM / COLMS / CLM
7 CLMS / CSAVE / D / D2 / D4 / DAGE
8 DU / DELIM / DELI / DELIS / DELIM / DELI2
9 COMMON DELOS / DELSI / DELSO / DELTE / DELT / DELV2
DEIAGB / DEMAG / DEMGB / DEMGB / DEMGB / DEMGB
DEISIS / DESOS / DO / OF1 / OF / OF1
2 DEI / DRO / DR / DS1 / DSAY / DSAY / DSAY2
3 DEIMAX / DSMIN / DSMIN / DSMIN / DSMIN / DSMIN
4 COMMON DSES / DS / DSX1 / DSX2 / DSX1 / DSX2
DT / DTHI / DTHO / DTHO / DTHO / DTHO
6 COMMON DT / DTHSQ / DTHSQ / DTHSQ / DTHSQ / DTHSQ
DYO / DB / DB / DB / DB / DB
8 DYS / DMB / DMB / DMB / DMB / DMB
9 DML / DML / DML / DML / DML / DML
COMMON H / HJT / HKAG / HKAG / HKAG / HKAG2
1 HKGM / HKMS / HLA1 / HLA1 / HLA1 / HLA1
2 HLB1 / HLB1 / HLB1 / HLB1 / HLB1 / HLB1
3 HOPE / HT / IACV / IACV / IACV / IACV
4 COMMON IGR / INT / ISFT / IZERO / K / K1
K2 / KAP / KDSCT / KDS / KDS / KDS
6 KR / KTRCT / KTR / KTR / KTR / KTR
7 L1 / L2 / LCT1 / LCT2 / LL / LCTCT
8 LSW / LSW / LSW / LSW / LSW / LSW
9 COMMON MOP / MAT / MACV / MT / NCLK / NCT5
NDIAG / NDS / NDS / NDS / NDS / NDS
1 NVA / NVA / NVA / NVA / NVA / NVA
2 NRSOO / NRSO / P11 / P11 / P11 / P11
3 PAS / PBJ / PMBE / PMBE / PMBE / PMBE
4 COMMON PBS / PHIA3 / PHIDA / PHID / PINT / PL
PL1 / PO / PS / PS / PS / PS
7 R1 / RA / RAS / RAS / RAS / RAS
8 PC / RDELIN / RDELIN / RDELIN / RDELIN / RDELIN
9 COMMON REM / REMS / RESLIN / RESO / RESZ / RHOGB
RHOG / RHOCS / RHOLB / RHOLB / RHOLB / RHOLB
1 RIM / RI / RM / RM / RM / RM
2 ROBL / ROM / RO / RO / RO / RO
3 RVB / RV / RVS / S / S1 / S2

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52C4 3440
52C4 3450
52C4 3460
52C4 3470
52C4 3480
52C4 3490
52C4 3500
52C4 3510
52C4 3520
52C4 3530
52C4 3540
52C4 3550
52C4 3560
52C4 3570
52C4 3580
52C4 3590
52C4 3600
52C4 3610
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52C4 3650
52C4 3660
52C5 3670
52C5 3680
52C5 3690
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52C5 3720
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52C5 3770
52C5 3780
52C5 3790
52C5 3800
52C5 3810
52C5 3820
52C5 3830
52C5 3840
52C5 3850
52C5 3860
52C5 3870
52C5 3880
52C5 3890
52C5 3900
52C5 3910
52C5 3920
52C5 3930
52C5 3940
52C5 3950
52C5 3960
52C5 3970
52C5 3980
52C5 3990
52C5 4000
52C5 4010
52C5 4020
52C5 4030
52C5 4040
52C5 4050
52C5 4060
52C5 4070
52C5 4080
52C5 4090
52C5 4100
52C5 4110
52C5 4120
52C5 4130
52C5 4140
52C5 4150
52C5 4160
52C5 4170
52C5 4180
52C5 4190
52C5 4200
52C5 4210
52C5 4220
52C5 4230
52C5 4240
52C5 4250
52C5 4260
52C5 4270
52C5 4280
52C5 4290
52C5 4300
52C5 4310
52C5 4320
52C5 4330
52C5 4340
52C5 4350
52C5 4360
52C5 4370
52C5 4380
52C5 4390
52C5 4400
52C5 4410
52C5 4420
52C5 4430
52C5 4440
52C5 4450
52C5 4460
52C5 4470
52C5 4480
52C5 4490
52C5 4500

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4 COMMON S3 , S4 , SA , SB , SGN , ST ; SEC5 J510
5 STGS , SMIN , SMJ1 , SMJ2 , SMLC , SMLD , SEC5 J520
6 SMLE , SMLP , SMLG , S4 , SOJ1 , SOT2 , SEC5 J530
7 SOP , SO , SOSM , SS , SOJ1 , S20 , SEC5 J540
8 T , TB , TBRAY , TBRAY1 , TGM3 , TGI , SEC5 J550
9 TG , TGS , THIM , THIO , TH1 , THIS , SEC5 J560
COMMON THOM , THOU , THO , THOS , PK , TKT , SEC5 J570
1 TLM , TLO , TLT , TST , TLM , SEC5 J580
2 TLM , TLO , TLM , TLM , V1 , V2 , VAR , SEC5 J590
3 TLM , TLO , TLM , TLM , V1 , V2 , VAR , SEC5 J600
4 VBS , VBO , VGO , VGO , VGO , VGO , VGO , SEC5 J610
COMMON VIALB , VIAL , VIRG , VIBL , VIRL , VIRL , SEC5 J620
6 VIGMS , VILB , VILM , VILM , VILM , VILM , SEC5 J630
7 VL , VLSQ , VLS , VLS , VLS , VLS , SEC5 J640
8 WAT , WAT , WAT , WAT , WAT , WAT , SEC5 J650
9 WAT , WAT , WAT , WAT , WAT , WAT , SEC5 J660
COMMON XINT , XP , XS , XX , X10 , X11 , XCLK , SEC5 J670
1 XINT , XP , XS , XX , X10 , X11 , XCLK , SEC5 J680
2 YIS , YO , YOS , ZZZ , NSTMT , YI , SEC5 J690
DIMENSION PL(10) SEC5 J700
DIMENSION NDRAW(75) SEC5 J710
DIMENSION DATE(5), CASE(3), QID(8), XP(2,75), PL(10), Y SEC5 J720
1 C(6), AP(2,75), AXA(4), DSRAT(100), DSRAY(100), TERAY(100), TBRAY SEC5 J730
21(100), DPA(75), DT(14), DINT(4) SEC5 J740
EQUIVALENCE (NDRAW(1), DPA(1)) SEC5 J750
IF (NSTMT-70) 1,70,2 SEC5 J760
1 CALL DIME SEC5 J770
2 IF (NSTMT-100) 1,100,3 SEC5 J780
3 IF (NSTMT-149) 1,149,1 SEC5 J790
***** STATEMENT NO. 70 *****
C
DELTA S ITERATION ROUTINE.
70 CONTINUE
NSTMT=9999
16004 CONTINUE
IF (SOS1) 25070,25060,25070
25060 CONTINUE
S=1.0E-6
C FOLLOWING STATEMENT SIMPLIFIED BY UNIVAC.
SO=-SIGN(1.0,DP*ZZZ) ... ETC.
25070 CONTINUE
IF (SOS) 2470,2399,2470
2470 CONTINUE
DSMIN=1.0E-6-2.0*(S*(1.0+R)/R)
DSMAX=1.0E-6-1.0E-6
DSLIN=DSMIN
IF (DS) 3060,3010,3010
3000 CONTINUE
DSLI=DSMAX
3010 CONTINUE
IJH=1
SM=0.0
GO TO 16000
3030 CONTINUE
IJH=2
RFSO=SOS*
SMJ1=SM
SOJ1=SO
SM=DSLIN
GO TO 16000
3031 CONTINUE
PSLI=SOS*
SMJ2=SM
SOJ2=SO
IF (RFSO*PSLI) 3060,3060,3060
3060 CONTINUE
WRITE (6,3061) DSLIM,DP
GO TO 3090
3071 CONTINUE
RFS2=SOS*
SEC5 J910
SEC5 J920
SEC5 J930
SEC5 J940
SEC5 J950
SEC5 J960
SEC5 J970
SEC5 J980
SEC5 J990
SEC5 J1000
SEC5 J1010
SEC5 J1020
SEC5 J1030
SEC5 J1040
SEC5 J1050
SEC5 J1060
SEC5 J1070
SEC5 J1080
SEC5 J1090
SEC5 J1100
SEC5 J1110
SEC5 J1120
SEC5 J1130
SEC5 J1140
SEC5 J1150
SEC5 J1160
SEC5 J1170
SEC5 J1180
SEC5 J1190
SEC5 J1200

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SZO=SO
SZ=SM
HOPE=RESC*RESSZ
IF (HOPE) 3080,3085,3085
3080 CONTINUE
RSLIM=RESSZ
DSLIM=ZZM
SOJ2=70
GO TO 3090
3085 CONTINUE
RESSO=RESSZ
SMJ1=ZZM
SOJ1=SZO
3090 CONTINUE
SM=(SMJ1+DSLIM)/2.0
IJH=J
16000 CONTINUE
IF (ABS(SM)-SMIN) 1390,1390,1391
1390 CONTINUE
SM=-SIGN(SMIN,DP)
1391 AM=1.0+(R*SM)/(1.0+R)
BM=1.0-SM/(1.0+R)
VBSQ=(-V1/AM)-(V2/BM)
VBMSQ=VBSQ+VBSQ/2.0
C
C WRITE DIAGNOSTIC IF VBM NON-POSITIVE.
C
IF (VBMSQ) 1250,1250,1251
1250 CONTINUE
WRITE (6,1250) SM,AM,BM,V1,V2,VBSQ,VBSQ,R,VBMSQ
LL=18
GO TO 1482
C
C COMPUTE VEM
C
1251 VBM=3067*(VBMSQ)
RE=0+VF*ABS(SM)
IF (RE-.000001) 1254,1253,1259
1258 CD=2.0/RE
GO TO 71
1259 IF (RE-.1) 1260,1260,1263
1263 IF (RE-.20000) 1261,1264,1264
1264 CD=0.15/RE
GO TO 71
1260 CD=24.0/RE
GO TO 71
1261 CD=EXP(3.271-0.8893*(ALOG(RE))+0.33417*
1 (ALOG(RE)**2)+.00144*(ALOG(RE)**3))
71 CONTINUE
***** STATEMENT NO. 80 *****
C
C OPTIMUM SM IS TO BE USED.
C
80 IF (RE-.1611) 1380,1380,1381
1380 CDP=1.0
GO TO 1384
1381 IF (RE-.4789) 1382,1382,1383
1382 CD=1.1137+.06334*(ALOG(RE))+.004329*((ALOG(RE))**2)
GO TO 1384
1383 CDP=2.0
1384 SMLC=(C1*(SM**2))/(VBMSQ*CD)
SMLD=(7HCL*(SM**2))/(RHOG*(AM**2))
SMLG=((RHOL*(SM**2))/(RHOG*AM*(1.0+R)))+(
1 ((BM)/(1.0+R))-1.0
SMLF=SMLC*((1.0+AM)/(R*BM))+1.0+1.0
JHH 8/19/66
ZZZ=SMLF*SMLG*SM+SMLD*CDP
SO=-SIGN(1.0,DP*ZZZ)
C2=2.0*SMLG*SMLD
C2=SMLC*ZZZ/C2
IF (C2-LT-JJ) C2=ABS(C2)

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C2 = C2*.33333	SEC5 1896
S0 = S0*C2	SEC5 1898
S0SM = SC-SM	SEC5 1900
81 IF (ABS (SC-SM) - ESO) 1481, 1481, 1482	SEC5 1910
1481 NIS=NISO	SEC5 1920
NISO=0	SEC5 1930
GO TO 16	
GO TO 42	
C*****THIS IS TO BYPASS ITERATION COUNTER DURING PLOTTING IJH = 4	SEC5 1950
1482 CONTINUE	SEC5 1960
11482 NISO = NISO + 1	SEC5 1980
16060 IF (NISO-NSO) 1483, 1483, 1490	SEC5 1990
C	SEC5 2010
STORE THIS VALUE OF DS1 AND WRITE DS1 ARRAY IF FULL.	SEC5 2020
C	SEC5 2030
1483 CONTINUE	SEC5 2040
C*****DEBUGGING AID FOR BINARY CUT CONVERGENCE	SEC5 2050
DSRAY(KDS)=222222222.	SEC5 2060
DSRAY(KDS+1) = SCJ1	SEC5 2070
DSRAY(KDS+2) = SCJ1	SEC5 2080
DSRAY(KDS+3) = RISO	SEC5 2090
DSRAY(KDS+4) = SM	SEC5 2100
DSRAY(KDS+5) = S0	SEC5 2110
DSRAY(KDS+6) = S0SM	SEC5 2120
DSRAY(KDS+7) = DSLLH	SEC5 2130
DSRAY(KDS+8) = SCJ2	SEC5 2140
DSRAY(KDS+9) = RSLLH	SEC5 2150
KDS = KDS + 10	SEC5 2160
IF(KDS - 100) 16003, 16003, 1484	SEC5 2170
1484 WRITE (16) DSRAY	SEC5 2180
KDSCT=KDSCT+1	SEC5 2190
DO 1486 I=1, 100	SEC5 2200
DSRAY(I)=0.0	SEC5 2210
1486 CONTINUE	SEC5 2220
KDS=1	SEC5 2230
16003 CONTINUE	SEC5 2240
GO TO (3010, 3031, 3071), IJH	SEC5 2250
C*****END OF BINARY CUT CONVERGENCE ROUTINE	SEC5 2260
C	SEC5 2270
NO CONVERGENCE ON DS - PRINT DIAGNOSTIC AND GET ALL	SEC5 2280
PREVIOUS VALUES OF DS FROM TAPE 15 AND TEMPORARY STORAGE IN	SEC5 2290
DSRAY. PRINT THEM AND EXIT TO DIAGNOSTIC ROUTINE.	SEC5 2300
C	SEC5 2310
1490 REWIND 16	
NST=79299	
WRITE (6, 1490)	SEC5 2340
1491 IF (KDSCT/1493, 1493, 1492	SEC5 2350
1492 READ (16) DSRAY1	SEC5 2360
WRITE (6, 1491) (DSRAY1(I), I=1, 100)	SEC5 2370
KDSCT=KDSCT-1	SEC5 2380
GO TO 1491	SEC5 2390
1493 WRITE (6, 1491) (DSRAY(I), I=1, KDS)	SEC5 2400
KDS=1	SEC5 2410
KDSCT=0	SEC5 2420
DO 1495 I=1, 100	
DSRAY(I)=0.0	SEC5 2440
1495 CONTINUE	SEC5 2450
LL=18	
REWIND 16	SEC5 2460
GO TO 500	
C	SEC5 2480
OPTIMIZE DS AND DX.	SEC5 2490
C	SEC5 2500
82 IF (MFO-1) 2382, 2381, 2382	SEC5 2510
2381 DS=0.0	SEC5 2520
S=S0	SEC5 2530
MFO=0	SEC5 2540
GO TO 93	SEC5 2550
2382 DS=S0-SOF	SEC5 2560
83 SO2=S0	SEC5 2570
DX=(D/(0.75*RHO*ABS(SM)*SM*CD*VHMSQ))	SEC5 2580
1 * (4633.04*DP+((BM**2)*RHO*DVHSSQ)/2.0)	SEC5 2590
	SEC5 2600


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2      + ((RM*BHOL*VBMSQ)/(1.0+R))*(((2.0*SM*DT)/(1.0+R))-DS))
100 DS1=DS
    NSTMT=9999
    VBSQ=VBSCQ+DVBSQ
    IF (VBSQ) 300,300,301
300 WRITE (6,9300)
    LL=19
    GO TO 500
C
C      STORE M+DPCINT QUANTITIES FOR NEXT END-POINT.
C
301 RMLM=RML
    RHCLM=RHCL
    DELTM=TG-TL
    VLM=VM*VEM
    HLAM=HLA
    HLEM=HLB
    RM=R
C
C      DETERMINE HEAT TRANSFER COEFFICIENT.  SEGMENTS ARE NOT
C      CONTINUOUS AT JUNCTIONS.
C
    IF (REM-1.0) 304,304,305
304 HM=(24.2*HKG/M)/D
    GO TO 309
305 IF (REM-25.0) 306,306,307
306 HM=3600.*CGM*PHO.3*(ABS(SM))*VBM*
    1 ((2.2/RE)*(.48/(SQRT(RE))))
    GO TO 309
307 HM=(4.44*HKG/M*(REM*.6))/D
C
C      COMPUTE MEAN BOUNDARY-LAYER PARAMETERS FOR CIRCULAR NOZZLE
C      OR OUTER WALL OF ANNULAR NOZZLE.
C
308 THOM=1H0*DTMO/2.0
    DELOM=10.286*THOM
    IF (RDELON.LT.0.0) RDELOM=ABS(RDELOM)
    CFOM=.208/((ALOG10(RDELOM)+.425)**2.584)
    IF (MGEO) 309,30,309
309 THIM=T+1*DTMI/2.0
    DELIM=10.286*THIM
    RDELIM=(300.*PHOL*VL*DELIM)/VILM
    CFIM=.208/((ALOG10(RDELIM)+.425)**2.584)
30 NSTMT=30
    RETURN
2399 NSTMT=2399
    RETURN
500 NDIAG=1
    CALL OUTPUT(NNN,LPGCT,MGEO)
    NSTMT=110
    RETURN
9250 FORMAT(1H,7X,15HNONPOSITIVE VEM/(1H ,9X,1PE15.6))
9300 FORMAT(1H,7X,14HNONPOSITIVE VBI
9490 FORMAT(1H,7X,24HCOULD NOT CONVERGE ON DS,/)
9491 FORMAT(1H ,1PE12.4)
3061 FORMAT(1H,3BHILK? SIGN RESIDUES IN INTERVAL 0 TO ,1PE12.4,
10HFOR DP = ,E15.4)
    END
C
C      SUBROUTINE SECT6
C
COMMON TZZZAY
DIMENSION TZZZAY(1120)
THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRF
IT MUST BE THE FIRST COMMON BLOCK
C
COMMON A , ABAR , ALAM , ALEHAB , ALPHA , ALPHAB ,
1 ALPHS , AM , AP , AS , AT , BA ,
2 BB , BETAB , BETAMB , BETA , BETAS , BM ,
3 C , C1 , CAG1 , CAGMB , CAG , CALAB ,
4 CBG1 , CAL , CASE , CGBMB , CBG , CBUMB , CSL ,
COMMON CDMS , CDP , CD , CPIM , CPTMS , CDM ,
6 CFOMS , CGMB , CGM , CGMS , CLMB , CL1 ,
7 CLAS , CSAVE , D , D2 , DA , DATE ,

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      EMAGB=EMAG+DEMAGB
      ENGB=ENEG+DENRGB
      DTGB=TB-TG
      TLMB=(TL+TB)/2.0
      TGMB=(TG+TB)/2.0
      PAMB=(PA+PAB)/2.0
      PSMB=(PB+PBB)/2.0

      INTERPOLATE INTO SPECIFIC HEAT TABLES FOR
      CALMB - SPECIFIC HEAT - LIQUID A
      CBLMB - SPECIFIC HEAT - LIQUID B
      CAGMB - SPECIFIC HEAT - GAS A
      CBGMB - SPECIFIC HEAT - GAS B

      N=5
      NN=5
      CALL INTERP(CALMB,N,TLMB,P)
      IF(N) 340,340,341
340  WRITE (6,9136) HT(NN),TLMB,P
      LL=25
      GO TO 500
341  N=6
      NN=6
      CALL INTERP(CBLMB,N,TLMB,P)
      IF(N) 340,340,343
343  N=1
      CALL INTERP(CAGMB,N,TGMB,PAB)
      IF(N) 344,344,345
344  LL=25
      WRITE (6,9136) HT(NN),TGMB,PAB
      GO TO 500
345  N=2
      NN=2
      CALL INTERP(CBGMB,N,TGMB,PBB)
      IF(N) 346,346,347
346  LL=25
      WRITE (6,9136) HT(NN),TGMB,PBB
      GO TO 500
347  ALPHMB=(ALPHA+ALPHAB)/2.0
      BETAMB=(BETA+PETAB)/2.0
      CMB=(ALPHMB*CALMB)+(1.0-ALPHMB)*CBLMB
      CGMB=(1.0-BETAMB)*CAGMB+BETAMB*CBGMB
      DTLB=(-1.0/(B*CLMB))*((CGMB-DTGB)*
1      ((VBSQ-VG**2)+2.0*((VBSQ-VL**2))/50072.9)+
2      ((DEGATB/ENGB)*(HLA+CAG*(TG-TL)))+
3      ((DEGGB/ENGB)*(HLB+CBG*(TG-TL)))+
4      ((DEGGB/ENGB)*((VGB**2)-(VL**2))/50072.9)))

      TEST FOR CONVERGENCE ON TB.
      IF (ABS((TD-TL)-DTLB))-EB) 141,141,350
350  NNE=NNB+1
      IF (NNE-NE) 351,351,354

      SAVE THIS VALUE OF TB FOR POSSIBLE NON-CONVERGENCE.

351  TB=TL+DTLB
      TBAY(KTB)=TB
      KTB=KTB+1
      IF (KTB-100) 140,140,352
352  WRITE (14) TBAY
      DO 353 I=1,100
      TBAY(I)=0.0
353  CONTINUE
      KTB=1
      KTBCT=KTBCT+1
      GO TO 140

      NO CONVERGENCE ON TB AND ITERATION MAXIMUM REACHED.
      PRINT DIAGNOSTIC AND ALL VALUES OF TB FOUND.

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SEC6 1590
SEC6 1600
SEC6 1610
SEC6 1620
SEC6 1630
SEC6 1640
SEC6 1650
SEC6 1660
SEC6 1670
SEC6 1680
SEC6 1690
SEC6 1700
SEC6 1710
SEC6 1720
SEC6 1730
SEC6 1740
SEC6 1750
SEC6 1760
SEC6 1770
SEC6 1780
SEC6 1790
SEC6 1800
SEC6 1810
SEC6 1820
SEC6 1830
SEC6 1840
SEC6 1850
SEC6 1860
SEC6 1870
SEC6 1880
SEC6 1890
SEC6 1900
SEC6 1910
SEC6 1920
SEC6 1930
SEC6 1940
SEC6 1950
SEC6 1960
SEC6 1970
SEC6 1980
SEC6 1990
SEC6 2000
SEC6 2010
SEC6 2020
SEC6 2030
SEC6 2040
SEC6 2050
SEC6 2060
SEC6 2070
SEC6 2080
SEC6 2090
SEC6 2100
SEC6 2110
SEC6 2120
SEC6 2130
SEC6 2140
SEC6 2150
SEC6 2160
SEC6 2170
SEC6 2180
SEC6 2190
SEC6 2200
SEC6 2210
SEC6 2220
SEC6 2230
SEC6 2240
SEC6 2250
SEC6 2260
SEC6 2270
SEC6 2280
SEC6 2290
SEC6 2300

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[illegible]

C SUBSTITUTION ROUTINE AT STEP 90.

```

C
2399 KDSCT=0
      NSINT=9999
      IBLW=0
      KDS=1
      SNGS=0
      SGN=0.5
      DSMIN=1.0E-6-2.0*(S+(1.0+R)/R)
      DCMAX=1.0+R-1.0E-6
12399 CONTINUE
      DS1=DSMIN
      IBW=1
      GO TO 5000
2401 CONTINUE
      DSX1=DS1
      DSRES1=DSRES
      DS1=DSMAX
      IBW=2
      GO TO 5000
2402 CONTINUE
      DSX2=DS1
      DSRES2=DSRES
      IF (IBLX) 12402, 2403, 12402
12402 CONTINUE
      DS1=DSAVE
      GO TO 12403
2403 CONTINUE
      DS1=DSX1-DSRES1*(DSX2-DSX1)/(DSRES2-DSRES1)
      IBLX=1
12403 CONTINUE
      IBW=3
      GO TO 5000
2404 CONTINUE
      IF (DSRES*DSRES1) 2405, 2406, 2406
2405 CONTINUE
      DSRES2=DSRES
      DSX2=DSX1
      SGN=-1.0*SGN
      GO TO 2407
2406 CONTINUE
      DSRES1=DSRES
      DSX1=DSX1
2407 CONTINUE
      IF (SGN) 12407, 2408, 2408
12407 CONTINUE
      DS1=DSX2
      GO TO 2409
2408 CONTINUE
      DS1=DSX1
2409 CONTINUE
      DS1=DS1+SGN
      IF (DS1-DSMAX) 2410, 2410, 5060
2410 CONTINUE
      IF (DS1-DSMIN) 5060, 12410, 12410
12410 CONTINUE
      IBW=4
      GO TO 5000
12411 CONTINUE
      IF (SGN) 12414, 12412, 12412
12412 CONTINUE
      IF (DSRES*DSRES2) 2406, 12413, 12413
12413 CONTINUE
      DSRES2=DSRES
      DSX2=DSX1
      GO TO 12416
12414 CONTINUE
      IF (DSRES*DSRES1) 12417, 12415, 12415
12415 CONTINUE
      DSRES1=DSRES
      DSX1=DSX1
12416 CONTINUE

```

```

SBC6 1050
SBC6 1060
SBC6 1070
SBC6 1080
SBC6 1090
SBC6 1100
SBC6 1110
SBC6 1120
SBC6 1130
SBC6 1140
SBC6 1150
SBC6 1160
SBC6 1170
SBC6 1180
SBC6 1190
SBC6 1200
SBC6 1210
SBC6 1220
SBC6 1230
SBC6 1240
SBC6 1250
SBC6 1260
SBC6 1270
SBC6 1280
SBC6 1290
SBC6 1300
SBC6 1310
SBC6 1320
SBC6 1330
SBC6 1340
SBC6 1350
SBC6 1360
SBC6 1370
SBC6 1380
SBC6 1390
SBC6 1400
SBC6 1410
SBC6 1420
SBC6 1430
SBC6 1440
SBC6 1450
SBC6 1460
SBC6 1470
SBC6 1480
SBC6 1490
SBC6 1500
SBC6 1510
SBC6 1520
SBC6 1530
SBC6 1540
SBC6 1550
SBC6 1560
SBC6 1570
SBC6 1580
SBC6 1590
SBC6 1600
SBC6 1610
SBC6 1620
SBC6 1630
SBC6 1640
SBC6 1650
SBC6 1660
SBC6 1670
SBC6 1680
SBC6 1690
SBC6 1700
SBC6 1710
SBC6 1720
SBC6 1730
SBC6 1740
SBC6 1750
SBC6 1760

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[illegible]


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NSTIT=110
RETURN
5065 FORMAT (1H0,7X,51PNO DS CONVERGENCE.  COULD DETECT NO SIGN CHANGE2
1IN ,J4HPRESIDUALS OF F(DS).  VALUES FOLLOW / (10X,1P6E15.6))
9001 FORMAT (1H0,10X,20HNEGATIVE VBM50,SECT6 / (1X,1P6E15.6))
9136 FORMAT (1H0,7X,17HOUTSIDE RANGE OF , A6,7H TABLE.,5X,
14HT = ,1E12.4,5X,4HP = ,F12.4)
9310 FORMAT (1H0,7X,12HNEGATIVE PAD)
9312 FORMAT (1H0,7X,12HNEGATIVE PDB)
9318 FORMAT (1H0,7X,17HOUTSIDE RANGE OP ,A6,7H TABLE.,5X,
14HT = ,1E12.4,5X,4HP = ,F12.4)
9320 FORMAT (1H0,7X,12HINFINITE PAD)
9333 FORMAT (1H0,7X,14HNONPOSITIVE PR)
9352 FORMAT (1H0,7X,24HCOULD NOT CONVERGE ON TB)
9491 FORMAT (1H ,1P10E11.4)
END

SUBROUTINE THROAT
COMMON TZZZAY
DIMENSION TZZZAY(11200)
THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRO
IT MUST BE THE FIRST COMMON BLOCK
COMMON A ABAR ALAM ALPHAB ALPHA ALPHMB
1 ALPHS AM AP AS AT BETA B
2 DU BETAB BERAMB BETA B
3 CBG1 CAL CASE CBGMB CBGMB CALMB
4 COMMON CCM CCM CBGMB CBGMB CBGMB
6 CCM CCM CBGMB CBGMB CBGMB
8 CCM CCM CBGMB CBGMB CBGMB
9 CCM CCM CBGMB CBGMB CBGMB
1 COMMON DELS DELS DELS DELS DELS
2 DLS DLS DLS DLS DLS
3 DLS DLS DLS DLS DLS
4 DLS DLS DLS DLS DLS
5 DLS DLS DLS DLS DLS
6 DLS DLS DLS DLS DLS
7 DLS DLS DLS DLS DLS
8 DLS DLS DLS DLS DLS
9 DLS DLS DLS DLS DLS
1 COMMON H H H H H
2 H H H H H
3 H H H H H
4 H H H H H
5 H H H H H
6 H H H H H
7 H H H H H
8 H H H H H
9 H H H H H
1 COMMON K K K K K
2 K K K K K
3 K K K K K
4 K K K K K
5 K K K K K
6 K K K K K
7 K K K K K
8 K K K K K
9 K K K K K
1 COMMON L L L L L
2 L L L L L
3 L L L L L
4 L L L L L
5 L L L L L
6 L L L L L
7 L L L L L
8 L L L L L
9 L L L L L
1 COMMON M M M M M
2 M M M M M
3 M M M M M
4 M M M M M
5 M M M M M
6 M M M M M
7 M M M M M
8 M M M M M
9 M M M M M
1 COMMON N N N N N
2 N N N N N
3 N N N N N
4 N N N N N
5 N N N N N
6 N N N N N
7 N N N N N
8 N N N N N
9 N N N N N
1 COMMON P P P P P
2 P P P P P
3 P P P P P
4 P P P P P
5 P P P P P
6 P P P P P
7 P P P P P
8 P P P P P
9 P P P P P
1 COMMON Q Q Q Q Q
2 Q Q Q Q Q
3 Q Q Q Q Q
4 Q Q Q Q Q
5 Q Q Q Q Q
6 Q Q Q Q Q
7 Q Q Q Q Q
8 Q Q Q Q Q
9 Q Q Q Q Q
1 COMMON R R R R R
2 R R R R R
3 R R R R R
4 R R R R R
5 R R R R R
6 R R R R R
7 R R R R R
8 R R R R R
9 R R R R R
1 COMMON S S S S S
2 S S S S S
3 S S S S S
4 S S S S S
5 S S S S S
6 S S S S S
7 S S S S S
8 S S S S S
9 S S S S S
1 COMMON T T T T T
2 T T T T T
3 T T T T T
4 T T T T T
5 T T T T T
6 T T T T T
7 T T T T T
8 T T T T T
9 T T T T T
1 COMMON U U U U U
2 U U U U U
3 U U U U U
4 U U U U U
5 U U U U U
6 U U U U U
7 U U U U U
8 U U U U U
9 U U U U U
1 COMMON V V V V V
2 V V V V V
3 V V V V V
4 V V V V V
5 V V V V V
6 V V V V V
7 V V V V V
8 V V V V V
9 V V V V V
1 COMMON W W W W W
2 W W W W W
3 W W W W W
4 W W W W W
5 W W W W W
6 W W W W W
7 W W W W W
8 W W W W W
9 W W W W W
1 COMMON X X X X X
2 X X X X X
3 X X X X X
4 X X X X X
5 X X X X X
6 X X X X X
7 X X X X X
8 X X X X X
9 X X X X X
1 COMMON Y Y Y Y Y
2 Y Y Y Y Y
3 Y Y Y Y Y
4 Y Y Y Y Y
5 Y Y Y Y Y
6 Y Y Y Y Y
7 Y Y Y Y Y
8 Y Y Y Y Y
9 Y Y Y Y Y
1 COMMON Z Z Z Z Z
2 Z Z Z Z Z
3 Z Z Z Z Z
4 Z Z Z Z Z
5 Z Z Z Z Z
6 Z Z Z Z Z
7 Z Z Z Z Z
8 Z Z Z Z Z
9 Z Z Z Z Z

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6	CFOMS	CGMB	CGM	CGMS	CLMB	CLM	DIAG0110
7	CLMS	CSAVE	D	D2	DA	DATE	DIAG0140
8	DD	DELIM	DELI	DELIS	DELOM	DELO	DIAG0150
9	DELOS	DELSI	DFLSO	DELFM	DELT	DELV2	DIAG0160
COMMON	DEMAGB	DEMAG	DEMGB	DEMGB	DEMB	DINT	DIAG0170
1	DILIS	DLSOS	DO	DP1	DP	DRAY	DIAG0180
2	DPI	DRO	DR	DS1	DSAVE	DSLIM	DIAG0190
3	DSMAX	DSMIN	DSRAY1	DSRAY	DSRES1	DSRES2	DIAG0200
4	DSRFS	DS	DSX1	DSX2	DTG1	DTG2	DIAG0210
COMMON	DTG	DTHT	DTNO	DTL1	DTLB	DIL	DIAG0220
6	DT	DVBSQ	DVGSQ	DVLSQ	DX	DY1	DIAG0230
7	DYO	EB	EDS	EMAGB	EMAG	EMGB	DIAG0240
8	EMGB	EMGB	EMG	EMGS	EML3	EMLM	DIAG0250
9	EML	EMLS	EMT	ESO	FLERP	FOX	DIAG0260
COMMON	H	HJI	HYAG	HYBG	HXGM1	HXGM2	DIAG0270
1	HKGM	HKGM5	HLA1	HLAM	HLA	HLAS	DIAG0280
2	HLB1	HLBM	HLR	HLRS	HM	HAS	DIAG0290
3	HOPE	HT	IACV	IBL4	IBLX	IBW	DIAG0300
4	IQH	INT	ISCT	IZERO	K	K1	DIAG0310
COMMON	K2	KAP	KDSC	KOS	KL	KR1	DIAG0320
6	KR	KTBCT	KX1	KXP1	KXP	L	DIAG0330
7	L1	L2	LCT1	LCT2	LL	LGGCT	DIAG0340
8	LSW	LSU	MTDO	MTD	MTFO	MM	DIAG0350
9	MOD	MTIT	NACV	N3	NCLK	NCT5	DIAG0360
COMMON	NDIAG	NDS	NNGS	NTB	NCLK	NLST	DIAG0370
1	NNA	NNB	NNDS	NNN	NMP	NN	DIAG0380
2	NH100	NH50	NNS	NP	N50	NS	DIAG0390
3		P10	P11	PAB	PAMB	PA	DIAG0400
4	PAS	PBB	PBBB	PBOB	PBO	P3	DIAG0410
COMMON	PBS	PHIAB	PHIDA	PHI	PINT	PL	DIAG0420
6	PL1	PO	PS	PT	Q	QID	DIAG0430
7	R1	RA	PAS	RAXO	RAX	RB	DIAG0440
8	RC	RDELIM	RDELLOM	RDINS	RDOMS	RDF	DIAG0450
9	REM	REMS	REGLIM	RZSO	RESZ	RHGB	DIAG0460
COMMON	RHOG	RHOGS	RHOLB	RHOLM	RHOL	RHOLS	DIAG0470
1	RI	RI	ROALB	ROALB	ROAL	ROBLB	DIAG0480
2	ROBL	ROM	RO	R	RSLIM	RS	DIAG0490
3	RVB	RV	AVS	S	S1	S2	DIAG0500
4		S1N	SA	SB	STN	SIG	DIAG0510
COMMON	SIGS	S1N	SHJ1	SHJ2	SHLC	SHLO	DIAG0520
6	SMLZ	SMLF	SM	SOJ1	SOJ2	SOJ2	DIAG0530
7	SOP	SO	SO5M	SS	SZY	SZO	DIAG0540
8	T	TB	TBRAY	TBRAY1	TMB	TG	DIAG0550
9	TG	TGS	THIM	THIO	THI	THIS	DIAG0560
COMMON	THOM	THOD	THO	THOS	TK	TKT	DIAG0570
1	TLMB	TLQ	TL	TLG	TSZ	TWIM	DIAG0580
2	TLIMS	TLQ	TLMS	V1	V2	VAB	DIAG0590
3	VSD	VDSG	VDM	VDM5Q	V3	VBSO	DIAG0600
4	VBS	VGO	VG	VGSQ	VGS	VLAG	DIAG0610
COMMON	VIALB	VIAL	VITG	VILLB	VIL	VISM	DIAG0620
6	VIGMS	VILB	VILM	VILMS	VLM	VLO	DIAG0630
7	VL	VLSQ	VLS	VS	VSS	VAB	DIAG0640
8	WAG	WAGS	WAL	WGB	WGB	WBS	DIAG0650
9	WDL	WGB	WG	WGS	WIM	WIMS	DIAG0660
COMMON	WUM	WQS	X	X10	X11	XCLK	DIAG0670
1	XINT	XP	XS	XX	XXA	YI	DIAG0680
2	YES	YO	YOS	ZZZ	ZSTMT		DIAG0690
	DIMENSION CL(10)						DIAG0700
	DIMENSION NDRA(75)						DIAG0710
	DIMENSION DATE(5),CASE2(3),DID(8),XP(2,75),PL1(10),						DIAG0720
1	C(6),AP(2,75),XXA(9),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY						DIAG0730
2	21(100),DRAY(75),HT(18),DINT(8)						DIAG0740
	EQUIVALENCE (NDRA(1),DRAY(1))						DIAG0750
	IF(NSTMT-497)1,497,2						DIAG0760
1	CALL DUMF						DIAG0770
2	IF(NSTMT-529)1,529,1						DIAG0780
437	NSTMT=9999						DIAG0790
	IF(NDIAG-1)10,498,10						DIAG0800
498	DO 499 I=1,75						DIAG0810
	DRAY(I)=99999.						DIAG0820
499	CONTINUE						DIAG0830
	LSW=0						DIAG0840

	GO TO(501,502,503,504,505,506,507,508,509,510,511,512,513,514,	DIAG 0850
1	515,516,517,518,519,520,521,522,523,524,525,526,527,528,	DIAG 0860
2	529),LL	DIAG 0870
C	DIAGNOSTIC OUTPUT. ENTRY IS MADE TO SET CERTAIN	DIAG 0880
C	SETS OF OUTPUT VALUES INTO THE ARRAY DRAY DEPENDING	DIAG 0890
C	ON THE VALUE OF LL, WHICH IS SET IN VARIOUS POINTS THROUGHOUT	DIAG 0900
C	THE MAIN PROGRAM.	DIAG 0910
529	DRAY(54)=PEP	DIAG 0920
	NSI*=-9509	DIAG 0930
528	DRAY(45)=VILB	DIAG 0940
	DRAY(53)=Q	DIAG 0950
	DRAY(38)=ADAR	DIAG 0960
	DRAY(47)=RHOLB	DIAG 0970
527	DRAY(47)=RHOLB	DIAG 0980
526	DRAY(34)=THOGB	DIAG 0990
525	DRAY(44)=TULB	DIAG 1000
	DRAY(43)=TUGB	DIAG 1010
524	DRAY(37)=RJ	DIAG 1020
	DRAY(42)=BETAB	DIAG 1030
	DRAY(41)=ALPHAB	DIAG 1040
	DRAY(50)=WGB	DIAG 1050
	DRAY(49)=WGB	DIAG 1060
523	DRAY(48)=WGB	DIAG 1070
522	DRAY(52)=PBB	DIAG 1080
521	DRAY(51)=PAB	DIAG 1090
520	DRAY(72)=CFI	DIAG 1100
	DRAY(69)=DELEIM	DIAG 1110
	DRAY(71)=FIM	DIAG 1120
	DRAY(61)=CFIM	DIAG 1130
	DRAY(63)=DELOM	DIAG 1140
	DRAY(36)=HM	DIAG 1150
	DRAY(35)=CU	DIAG 1160
519	DRAY(34)=LEM	DIAG 1170
518	DRAY(63)=VBD	DIAG 1180
	DRAY(56)=40M	DIAG 1190
	DRAY(59)=DELSO	DIAG 1200
	DRAY(54)=DELO	DIAG 1210
	DRAY(57)=THO	DIAG 1220
	DRAY(62)=TDOM	DIAG 1230
	DRAY(58)=DELSI	DIAG 1240
	DRAY(67)=DELI	DIAG 1250
	DRAY(66)=THI	DIAG 1260
	DRAY(55)=4IM	DIAG 1270
517	DRAY(51)=A	DIAG 1280
	DRAY(12)=D	DIAG 1290
	DRAY(28)=SIG	DIAG 1300
516	DRAY(14)=RA	DIAG 1310
	DRAY(9)=VL	DIAG 1320
	DRAY(4)=VG	DIAG 1330
515	DRAY(1)=X	DIAG 1340
	DRAY(10)=CLM	DIAG 1350
	DRAY(29)=CGM	DIAG 1360
	DRAY(31)=VIGM	DIAG 1370
	DRAY(32)=VILM	DIAG 1380
	DRAY(33)=HKG M	DIAG 1390
	GO TO 1511	DIAG 1400
514	DRAY(33)=HKG M	DIAG 1410
	DRAY(32)=VILM	DIAG 1420
513	DRAY(31)=VIGM	DIAG 1430
	DRAY(29)=CGM	DIAG 1440
	DRAY(30)=CLM	DIAG 1450
512	DRAY(63)=VBD	DIAG 1460
	DRAY(56)=WOM	DIAG 1470
	DRAY(59)=DELSO	DIAG 1480
	DRAY(54)=DELO	DIAG 1490
	DRAY(57)=THO	DIAG 1500
	DRAY(62)=TDOM	DIAG 1510
	DRAY(67)=DELSI	DIAG 1520
	DRAY(66)=DELI	DIAG 1530
	DRAY(66)=THI	DIAG 1540
		DIAG 1550
		DIAG 1560


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DPAY (65) =WIN
DPAY (5) =A
DPAY (12) =D
DPAY (28) =SIG
DPAY (14) =PA
DPAY (9) =VL
DPAY (3) =VG
DPAY (1) =X
1511 DPAY (55) =YO
DPAY (54) =YI
511 DPAY (11) =S
DPAY (4) =VB
DPAY (10) =VS
DPAY (5) =A
DPAY (27) =HLD
510 DPAY (26) =HLA
509 DPAY (11) =RV
DPAY (14) =DML
DPAY (17) =FMS
DPAY (23) =RHOL
508 DPAY (17) =RHOG
DPAY (3) =R
507 DPAY (16) =BETA
DPAY (15) =ALPHA
DPAY (23) =WG
DPAY (22) =WEG
506 DPAY (21) =WAG
505 DPAY (25) =PB
504 DPAY (24) =PA
503 DPAY (7) =IL
502 DPAY (6) =IG
501 DPAY (2) =F
NDPAY (72) =NNA
NDPAY (73) =NIS
NDPAY (74) =NIB
IF (NDIAG-1) 540,550,540
540 WRITE (11) DPAY
NNA=NNA+1
DPAY (12) =0.0
WRITE (14) (DPAY (J), J=1, 10)
NNA=NNA+1
GO TO 63
C
DIAGNOSTIC OUTPUT - VARIABLES NOT YET COMPUTED THIS
ITERATION ARE SET TO 1085. PRINT OUT NINE LINES
OF OUTPUT.
550 WRITE (6,1001) (DPAY (I), I=1, 9)
551 WRITE (6,1002) (DPAY (I), I=10, 18)
552 WRITE (6,1003) (DPAY (I), I=19, 27)
553 WRITE (6,1004) (DPAY (I), I=28, 36)
554 WRITE (6,1005) (DPAY (I), I=29, 45)
555 WRITE (6,1006) (DPAY (I), I=46, 54)
556 WRITE (6,1007) (DPAY (I), I=55, 63)
557 WRITE (6,1008) (DPAY (I), I=64, 71)
558 CONTINUE
4 WRITE (6,1009) NNA,NIS,NIB
10 NSENT=10
22000
63 NSENT=63
RETURN
C
FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
1001 FORMAT (1H0,13X,14X,13X,1H5,13X,14H,12X,2HW3,13X,1HA,12X,2HTG,12X,
12HLL,12X,2HVG,12X,2HVL,/,6X,3E06.4)
1002 FORMAT (1H0,12X,2HVS,13X,1HS,13X,1H0,12X,2HVV,12X,2HFA,9X,
15HALLHA,10X,4HETA,12X,2HVS,12X,2HVL,/,6X,3E14.4)
1003 FORMAT (1H0,11X,3HPOG,11X,3HGL,11X,3HWAG,11X,1HWBG,12X,2HWG,
112X,2HDA,12X,2HBL,12X,2HLA,12X,2HBL,/,6X,3E14.4)
1004 FORMAT (1H0,9X,5HSGNA,11X,3HCGM,11X,3HCL,10X,4HVIGM,10X,
14HVGMA,11X,3HGM,11X,3HREN,11X,3HCD,12X,2HHM,/,6X,3E9E14.4)

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1005 FORMAT(1H0,12X,2HFB,12X,2HAB,12X,2HTP,11X,3HVB,2X,5HALPHB,
19X,5HDETA,11X,3HGB,11X,3HGL,10X,4HVIL,/,6X,5E14.4)
1006 FORMAT(1H0,10X,4HPOG,10X,4HROL,10X,4HAG,10X,4HGB,
111X,3HGP,11X,3HAP,11X,3HGB,11X,1H0,11X,3HGP,/,6X,5E14.4)
1007 FORMAT(1H0,12X,2HYO,11X,3HGB,11X,3HTO,10X,4HDELO,9X,5HDEL*0,
19X,5HEDDO,10X,4HCFOM,10X,4HTOM,11X,3HVB,/,6X,5E14.4)
1008 FORMAT(1H0,12X,2HYI,11X,3HGB,11X,3HTI,10X,4HDELI,9X,5HDEL*1,9X,
15HREDI,10X,4HCFIM,10X,4HTIM,/,6X,5E14.4)
1009 FORMAT(1H0,10X,3HNA,9X,3HNI,9X,3HNI,2X,3(6X,I6))
C1032 FORMAT(1H1,120X,5HPAGE,13,/,1X,15HREAR TWO-PHASE,
C 1 26H TWO-COMPONENT NOZZLE FLOW,/)
END
SUBROUTINE WRITE (DVGSQ,DTL,RHOL,DVLSQ,DEHAG,DEHAG,
1 DELV2,ENG,HLAG,CAG1,DELT,HLB1,CPG1,SM,AM,BM,DX,DS)
WRITE (5,731) DVGSQ,DTL,RHOL,DVLSQ,DEHAG,DEHAG,
1 DELV2,ENG,HLAG,CAG1,DELT,HLB1,CPG1,SM,AM,BM,DX,DS
RETURN
9231 FORMAT(1H0,12X,5HGVG,14X,3HDTL,12X,5HROL,12X,5HVL,12X,
15HDEHAG,12X,5HDEHAG,12X,5HDELV2,/,1X,1E7E17.6,/,15X,1HEG,14X,
1 3HLA1,13X,4HAG1,13X,4HDELT,14X,3HLB1,13X,4HCG1,
1 15X,2HSM,/,1X,7E17.6,/,
2 16X,2HAM,15X,2HBM,15X,2HDS,/,1X,7E17.6)
END
SUBROUTINE OUTPUT(N,LPG,MGO)
C SUBROUTINE TO READ SAVED PRINT LINES FROM LOGICAL
C TAPE 22 AND PRINT THEM ON FORTRAN OUTPUT TAPE.
DIMENSION DRAY(75),NDRAY(75)
EQUIVALENCE (DRAY(1),NDRAY(1))
REWIND 11
L=1
1 IP(N)99,99,2
2 READ (11)DRAY
IP(L),5,4
4 WRITE (6,1032) LPG
LPG=LPG+1
L=0
GO TO 6
5 WRITE (6,999)
L=1
6 WRITE (6,1001) (DRAY(I),I=1,9)
WRITE (6,1002) (DRAY(I),I=10,18)
WRITE (6,1003) (DRAY(I),I=19,27)
WRITE (6,1004) (DRAY(I),I=28,36)
WRITE (6,1005) (DRAY(I),I=37,45)
WRITE (6,1006) (DRAY(I),I=46,54)
WRITE (6,1007) (DRAY(I),I=55,63)
IP(MGO)7,8,7
7 WRITE (6,1008) (DRAY(I),I=64,71)
8 CONTINUE
WRITE (6,1009) (NDRAY(I),I=72,74)
N=N+1
GO TO 1
99 REWIND 11
RETURN
999 FORMAT(1H0,120X,5HPAGE,13,/,1X,15HREAR TWO-PHASE,
C1032 FORMAT(1H1,120X,5HPAGE,13,/,1X,15HREAR TWO-PHASE,
1001 FORMAT(1H0,13X,14X,11X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
12HTL,12X,2HVG,12X,2HVL,/,6X,5E14.4)
1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HVV,12X,2HRA,9X,
15HALPHA,10X,4HETA,12X,5HGB,12X,2HGL,/,6X,5E14.4)
1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,4HAG,11X,3HGB,12X,2HVG,
112X,2HGA,11X,2HPS,12X,3HLA,12X,2HDL,/,6X,5E14.4)
1004 FORMAT(1H0,10X,5HSGSA,11X,3HCG,11X,3HCL,10X,4HVIG,10X,
14HVIL,11X,3HAG,11X,3HRE,11X,3HCS,12X,2HVS,/,6X,5E14.4)
1005 FORMAT(1H0,12X,2HFB,12X,2HAB,12X,2HTP,11X,3HVB,2X,5HALPHB,
19X,5HDETA,11X,3HGB,11X,3HGL,10X,4HVIL,/,6X,5E14.4)
1006 FORMAT(1H0,10X,4HPOG,10X,4HROL,10X,4HAG,10X,4HGB,
111X,3HGP,11X,3HAP,11X,3HGB,11X,1H0,11X,3HGP,/,6X,5E14.4)
1007 FORMAT(1H0,12X,2HYO,11X,3HGB,11X,3HTO,10X,4HDELO,9X,5HDEL*0,
19X,5HEDDO,10X,4HCFOM,10X,4HTOM,11X,3HVB,/,6X,5E14.4)
1008 FORMAT(1H0,12X,2HYI,11X,3HGB,11X,3HTI,10X,4HDELI,9X,5HDEL*1,9X,
15HREDI,10X,4HCFIM,10X,4HTIM,/,6X,5E14.4)

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[illegible]

	K=1	TABL0470
	IF (L-35) 4,4,27	TABL0480
C	THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENST	TABL0490
15	IF (I-4) 16,17,17	TABL0500
16	L=1	TABL0510
	I = I + 1	TABL0520
	K=1	TABL0530
	GO TO 4	TABL0540
27	WRITE (6,927) I	TABL0550
	GO TO 37	TABL0560
17	CONTINUE	TABL0570
	REWIND 12	
	WRITE (12) XVP	TABL0580
	WRITE (12) TCAV1	TABL0590
	WRITE (12) TCAV2	TABL0600
C	NEXT CARD IS FIRST CARD OF TVAR ARRAY	TABL0610
	DO 36 I=1,14	TABL0620
	K=1	TABL0630
29	READ (5,901) (C(L),L=1,6)	TABL0640
	ICARD=ICARD+1	TABL0650
	DO 34 L=1,5,2	TABL0660
	IF (C(L)+C(L+1)-199999.) 32,30,30	TABL0670
30	TVAR(I,1,K)=100000.	TABL0680
	TVAR(I,2,K)=100000.	TABL0690
	GO TO 31	TABL0700
32	TVAR(I,1,K)=C(L)	TABL0710
	TVAR(I,2,K)=C(L+1)	TABL0720
	IF (K-1) 33,37,37	TABL0730
33	K=K+1	TABL0740
34	CONTINUE	TABL0750
	GO TO 29	TABL0760
38	CONTINUE	TABL0770
36	WRITE (12) TVAR	TABL0780
	CSAVE=1.0	TABL0790
	READ (5,901) (C(L),L=1,6)	TABL0800
	ICARD=ICARD+1	TABL0810
	DO 1036 I=1,6	TABL0820
1036	CSAVE = CSAVE + C(I)	TABL0830
	IF (CSAVE) 37,37,37	TABL0840
37	CALL INTER(4,20,1.0,P)	TABL0850
	CALL DUPE	TABL0860
	CALL PKII	TABL0870
1037	CONTINUE	
	ENCLOS 12	
	REWIND 12	
	RETURN	
900	FORMAT (1H0,7X,19HERROR IN INPUT DATA,1I6)	TABL0900
901	FORMAT (6E12,6)	TABL0910
927	FORMAT (1H0,7X,36HRECEEDING MAXIMUM TEMPERATURE INPUT ,	TABL0920
	17HFOR N =,13)	TABL0930
	END	TABL0940
	SUBROUTINE INTER(VAR,N,T,P)	TABL0950
C	IF N=0, READ IN ALL TABLES, SET UP T ARRAY, AND EXIT.	INTR0960
C	IF N=20 WRITE OUT ALL TABLES AND EXIT.	INTR0970
C	IF N=1 THRU 4, GET APPROPRIATE TABLES FROM TAPE,	INTR0980
C	INTERPOLATE FOR VALUE OF VAR AND EXIT.	INTR0990
C	IF N=5 THRU 13, INTERPOLATE FOR VALUE OF VAR AND EXIT.	INTR1000
	DIMENSION TVAR(14,2,90),TVAR1(35,4,35),TVAR2(35,4,35)	INTR1010
	1 TRAY(4,35),H(14)	INTR1020
	COMMON TVAR1,TVAR2,TVAR	INTR1030
	IB=0	INTR1040
	IF (N) 1,1,10	INTR1050
1	K=1	INTR1060
	REWIND 12	INTR1070
	READ (12) TRAY	INTR1080
	READ (12) TVAR1	INTR1090
	READ (12) TVAR2	INTR1100
C	T ARRAY HAS BEEN SET UP, NO. OF T RECORDS (K) IS SET, NOW	INTR1110
C	PROCEED TO BRING IN PERMANENT ARRAYS.	INTR1120

C	READ (12) TVAR	INTR 0220
	SETUP	INTR 0230
10	IF (N-20) 100, 12, 11	INTR 0250
11	WRITE (6, 911)	INTR 0260
	CALL EXIT	INTR 0270
C	WRITE OUT TABLES FOR N=20, T IS PAGE COUNT.	INTR 0280
12	CALL ADATA	INTR 0290
	LCT1=0	INTR 0300
	LPGCT=T	INTR 0310
	WRITE (6, 920) LPGCT	INTR 0320
	LPGCT=LPGCT+1	INTR 0330
	DO 30 L=1, 14	INTR 0340
13	NT=1	INTR 0350
14	TEST1=TVAR(L, 1, NT)+TVAR(L, 2, NT)	INTR 0360
	IF (TEST1-2.0*99999.) 15, 15, 16	INTR 0370
15	NT=NT+1	INTR 0380
	IF (NT-50) 14, 14, 1000	INTR 0390
16	TVAR(L, 1, NT)=0.0	INTR 0400
	TVAR(L, 2, NT)=0.0	INTR 0410
	IF (NT-1) 519, 520, 515	INTR 0420
C	40 WRITE THIS TABLE	INTR 0430
520	WRITE (6, 920) H(L)	INTR 0440
	LCT1=LCT1+4	INTR 0450
	GO TO 510	INTR 0460
515	NT=NT-1	INTR 0470
	WRITE (6, 916) H(L)	INTR 0480
	L1=1	INTR 0490
	L2=AMINO (R, NT)	INTR 0500
	LT=1	INTR 0510
18	WRITE (6, 918) H(L), (TVAR(L, 2, LK), LK=L1, L2)	INTR 0520
	WRITE (6, 919) (TVAR(L, 1, LK), LK=L1, L2)	INTR 0530
	IF (L2-NT) 19, 20, 20	INTR 0540
19	L1=L1+4	INTR 0550
	L2=AMINO (L2+8, NT)	INTR 0560
	LT=LT+1	INTR 0570
	GO TO 18	INTR 0580
20	LCT1=LT*4+LCT1	INTR 0590
530	IF (LCT1-52) 10, 21, 21	INTR 0600
21	WRITE (6, 923) LPGCT	INTR 0610
	LPGCT=LPGCT+1	INTR 0620
	LCT1=1	INTR 0630
30	CONTINUE	INTR 0640
	PEWIND 12	INTR 0650
	DATA H(1)/4H CAG/	INTR 0660
	DATA H(2)/4H CBG/	INTR 0670
	DATA H(3)/4H WAG/	INTR 0680
	DATA H(4)/4H WBG/	INTR 0690
	DO 50 L=1, 4	INTR 0700
	IF (TRAY (L, 1)-99999.) 29, 29, 50	INTR 0710
29	WRITE (6, 920) LPGCT	INTR 0720
31	WRITE (6, 916) H(L)	INTR 0730
	LPGCT=LPGCT+1	INTR 0740
	LCT1=1	INTR 0750
	DO 45 KK=1, 35	INTR 0760
	IF (TRAY (L, KK)-99999.) 32, 32, 45	INTR 0770
32	WRITE (6, 914) TRAY(L, KK)	INTR 0780
	LCT1=LCT1+1	INTR 0790
	NCT=1	INTR 0800
34	TEST1=TVAR1(KK, L, NCT)+TVAR2(KK, L, NCT)	INTR 0810
	IF (TEST1-2.0*99999.) 35, 36, 36	INTR 0820
35	NCT=NCT+1	INTR 0830
	IF (NCT-35) 34, 34, 1000	INTR 0840
36	NCT=NCT-1	INTR 0850
	L1=1	INTR 0860
	L2=AMINO (R, NCT)	INTR 0870
37	CONTINUE	INTR 0880
38	DO 63 LT=L1, L2	INTR 0890
	IF (TVAR2(KK, L, LT)-100000.) 63, 60, 63	INTR 0900
60	TVAR1(KK, L, LT)=0.0	INTR 0910
	TVAR2(KK, L, LT)=0.0	INTR 0920
63	CONTINUE	INTR 0930

FILE: TH3 FORTRAN 'A1 NAVAL POSTGRADUATE SCHOOL

```

39 WRITE (6,938) H(L), (TVAR2(KK,L,LT),LT=L1,L2)
WRITE (6,939) (TVAR1(KK,L,LT),LT=L1,L2)
LCT1=LCT1+3
IF (LCT1-52) 66,65,65
65 WRITE (6,922) LPGCT
LPGCT=LPGCT+1
LCT1=3
66 IF (L2-NCT) 40,41,41
40 L1=L1+8
L2=A*INO (L2+8,NCT)
GO TO 38
41 IF (LCT1-52) 45,42,42
42 WRITE (6,922) LPGCT
LPGCT=LPGCT+1
LCT1=3
45 CONTINUE
50 CONTINUE
IF (IB4-1) 1047,1046,1047
1046 N=0
1047 RETURN
C N=1 THEN 18 - INTERPOLATE ROUTINE
100 IF (N-4) 101,101,150
101 DO 104 I=1,35
IF (TPAY (N,I) -T) 104,105,105
104 CONTINUE
GO TO 140
105 IF (I-1) 106,120,106
106 IM1=I-1
TK=TPAY (N,IM1)
TK1=TPAY (N,IM1)
DO 107 J1=1,35
IF (TVAR1 (IM1,N,J1) -P) 107,107,108
107 CONTINUE
GO TO 120
108 IF (J1-1) 109,120,109
109 IF (TVAR1 (IM1,N,J1) +TVAR2 (IM1,N,J1) -2.0*99999.) 110,120,120
110 JM1=J1-1
DIFF1=TVAR1 (IM1,N,J1) -TVAR1 (IM1,N,JM1)
DIFF1=TVAR1 (IM1,N,J1) -P
PC1=-(DIFF1/DIFF1)*(TVAR2 (IM1,N,J1) -TVAR2 (IM1,N,JM1)) +
TVAR2 (IM1,N,J1)
DO 111 J2=1,35
IF (TVAR1 (I,N,J2) -P) 111,111,112
111 CONTINUE
GO TO 120
112 IF (J2-1) 113,120,113
113 JM2=J2-1
IF (TVAR1 (I,N,J2) +TVAR2 (I,N,J2) -2.*99999.) 114,120,120
114 DIFF1=TVAR1 (I,N,J2) -TVAR1 (I,N,JM2)
DIFF1=TVAR1 (I,N,J2) -P
PC2=-(DIFF1/DIFF1)*(TVAR2 (I,N,J2) -TVAR2 (I,N,JM2)) +TVAR2 (I,N,J2)
VAR=(P-TK1)/(TK-TK1)*(PC2-PC1)+PC1
130 RETURN
120 N=0
IB4=1
GO TO 12
150 N=N-4
IF (N-15) 155,1000,1000
155 CONTINUE
DO 151 I=1,50
IP=I
IF (TVAR (N,1,I) -T) 151,151,152
151 CONTINUE
GO TO 120
152 IF (TVAR (N,1,I) +TVAR (N,2,I) -2.0*99999.) 153,120,120
153 IF (I-1) 154,120,154
154 IP1=IP-1
VAR=((T-TVAR (N,1,IP1))/(TVAR (N,1,IP) -TVAR (N,1,IP1)))
1=(TVAR (N,2,IP) -TVAR (N,2,IP1)) +TVAR (N,2,IP1)
GO TO 130
1000 CONTINUE
CALL OUTPUT

```

INTR 1080
INTR 1090
INTR 1100
INTR 1110
INTR 1120
INTR 1130
INTR 1140
INTR 1150
INTR 1160
INTR 1170
INTR 1180
INTR 1190
INTR 1200
INTR 1210
INTR 1220
INTR 1230
INTR 1240
INTR 1250
INTR 1260
INTR 1270
INTR 1280
INTR 1290
INTR 1300
INTR 1310
INTR 1320
INTR 1330
INTR 1340
INTR 1350
INTR 1360
INTR 1370
INTR 1380
INTR 1390
INTR 1400
INTR 1410
INTR 1420
INTR 1430
INTR 1440
INTR 1450
INTR 1460
INTR 1470
INTR 1480
INTR 1490
INTR 1500
INTR 1510
INTR 1520
INTR 1530
INTR 1540
INTR 1550
INTR 1560
INTR 1570
INTR 1580
INTR 1590
INTR 1600
INTR 1610
INTR 1620
INTR 1630
INTR 1640
INTR 1650
INTR 1660
INTR 1670
INTR 1680
INTR 1690
INTR 1700
INTR 1710
INTR 1720
INTR 1730
INTR 1740
INTR 1750
INTR 1760
INTR 1770
INTR 1780
INTR 1790


```

CALL DUMF
RETURN
911 FORMAT(1H0,7X,33HILLEGAL CALLING SEQUENCE TO INTRP)
916 FORMAT(1H0,56X,11HINPUT TABLE,2X,A5,/)
918 FORMAT(1H0,A6,1P8E15.6)
919 FORMAT(1H,2X,4HTEMP,1P8E15.6)
920 FORMAT(1H1,/,120X,4HPAGE,2X,I1)
934 FORMAT(1H,40X,14HTEMPER(CORE) = ,F12.4,/)
938 FORMAT(1H0,3X,A6,1P8E15.6)
939 FORMAT(1H,3X,5HPRESS,1X,1P8E15.6)
9520 FORMAT(1H0,/,1H0,7X,16ANO INPUT FOR TABLE, A6)
END
C*****
SUBROUTINE DUMF
CALLEXIT
RETURN
END
C
C*****
SUBROUTINE ADATA
DIMENSION HT(18),H(14),HT1(19),H1(14)
COMMON HT,H
DATA HT1/4H CAG,4H CBG,4H WAG,4H WAG,4H CAL,
1 4H CBL,4H LA,4H LB,4H PBO,4HROAL,
2 4HROBL,4H KAG,4H KGG,4HVIAL,4HVIBL,
3 4HVYAG,4HVIBG,4H SIG/
DATA H1/4H CAL,4H CBL,4H HLA,4H HLB,4H PBO,
1 4HROAL,4HROBL,4H KAG,4H KGB,4HVIAL,
2 4HVIBL,4HVYAG,4HVIBG,4H SIG/
DO 10 I=1,18
HT(I)=HT1(I)
10 CONTINUE
DO 20 I=1,14
H(I)=H1(I)
20 CONTINUE
RETURN
END

```

```

INTR 1870
INTR 1810
INTR 1820
INTR 1830
INTR 1840
INTR 1850
INTR 1860
INTR 1870
INTR 1880
INTR 1890
INTR 1900
INTR 1910

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